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TRANSACTIONS

OF THE

ILLUMINATING ENGINEERING SOCIETY

FOUNDED IN LONDON 1909 INCORPORATED 1930

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32 VICTORIA STREET
LONDON SW1

NOTES ON RECENT MEETINGS AND EVENTS

General Meetings in London.

A meeting of the Society was held in the Lecture Theatre of the Institution of Mechanical Engineers (Storey's Gate, St. James's Park, London, S.W.1) on Tuesday, April 13. The chair was taken by the President at 7.30 p.m.

The minutes of the last meeting having been taken as read, the names of applicants for membership were presented in the usual way.

The President then called upon Mr. L. Jesty and Mr. G. T. Winch to present their paper entitled "Television Images: an Analysis of their Essential Qualities," which was illustrated by lantern slides and demonstrations. On the motion of the President a vote of thanks was accorded to the authors for their interesting paper.

An interesting discussion followed, in which the following took part: Mr. T. M. C. Lance, Mr. J. M. Waldram, Mr. J. S. Dow, Mr. G. H. Wilson, Mr. J. Denton, Mr. F. P. Bentham, Mr. J. Marris, Mr. L. S. Harley, and Mr. A. Cunnington.

After the authors had briefly replied to various points raised in the discussion, a demonstration of television sets took place.

Following the Annual General Meeting on May 19 (an account of which will be published in the *Transactions* in due course), a general meeting was held in the Lecture Theatre of the Institution of Mechanical Engineers, at which the chair was taken by the President.

Descriptions, illustrated by lantern slides, of a number of outstanding floodlighting installations were contributed by Mr. R. O. Ackerley, Mr. E. Stroud, Mr. J. G. Clark, and Mr. T. Catten, following which Mr. Percy Good gave a critical survey of the Coronation lighting, in which the installations previously described and others were examined and discussed, and some suggestions for future procedure were made.

After the President had conveyed the thanks of the meeting to the authors, a brief discussion ensued, in which Mr. R. S. Botsford (Canada), Mr. J. H. Dupin (New Zealand), and Mr. E. C. R. Porter took part.

Applications for Membership.

Elections Completed.

The names of the following applicants for membership were presented at the general meeting of the Society, held on April 13, and these gentlemen were formally declared members of the Society at the subsequent meeting on May 19:—

CORPORATE MEMBERS:—

Calvert, F. L.	337, Grange Road, Upper Norwood, LONDON, S.E.19.
Edwards, W. J.	2, Gunnersbury Crescent, LONDON, W.3.
Essenhigh, G. E. W.	32, Croft Road, Merton, LONDON, S.W.19.
Freedman, Paul	6, Hillside Gardens, Highgate, LONDON, N.6.
Sully, R. B.	Edmundsons' Electricity Corporation, Ltd., Thames House, Millbank, LONDON, S.W.1.

COUNTRY MEMBERS:—

Hind, H.	26, Netherby Street, Oldham, LANCS.
McMillian, Prof. W. H.	The Mining Department, University of Edinburgh, 79, Grassmarket, EDINBURGH.
Mackay, R. J.	65, St. Giles, OXFORD.
Rawll, R. H.	City of Birmingham Electric Supply Department, 14, Dale End, BIRMINGHAM.
Truman, H. F.	40/42, Bridge Street, Walsall, STAFFS.

ASSOCIATE:—

Biggam, Major J.	R.A.M.C. Headquarters Mess, Millbank, LONDON, S.W.1.

At the meeting on April 13 the names of those announced on March 9, which were published in the issue of the *Transactions* (Vol. II., No. 4, p. 50, April, 1937), were read again, and these applicants were formally declared members.

Elections Pending.

At the general meeting held on May 19, the names of the following applicants for membership were presented:—

CORPORATE MEMBERS:—

Baker, J. G. P.	83, Hampstead Way, LONDON, N.W.11.
Griffin, R. P.	Harcourts, Ltd., Newman Street, LONDON, W.1.

Local and Sectional Meetings.

A meeting of the Local Centre for the North-West Area, held in Manchester on March 23, was devoted to a general discussion on industrial lighting, in the course of which interesting contributions by Mr. J. D. Nettleton, Mr. A. W. A. Thurley, and Mr. S. H. Packer were presented.

"The Design of Industrial Lighting Fittings" formed the subject of an address given by Mr. W. R. Stevens at the meeting of the Industrial Lighting Section, held at the E.L.M.A. Lighting Service Bureau (London), on April 21, over which Mr. R. O. Ackerley presided. The address dealt in succession with the chief factors in industrial lighting, namely, amount of light, glare, shadow, maintenance, appearance, nature of light and cost, was supplemented by a number of effective demonstrations, and led to a keen and entertaining discussion.

SOME ASPECTS OF THE STREET LIGHTING PROBLEM

by S. ENGLISH, D.Sc., F.I.C., F.Inst.P.
(Holophane Research Laboratory), (Member).

(Paper read on Tuesday, March 9th, 1937.)

Of all branches of illumination, it is probable that street- and road-lighting is the one which has made the most spectacular advances during recent years. It is well that this is so, for several reasons—to mention only two: (a) In some quarters it appears to have been the cinderella of public services, since some authorities who are responsible for the lighting of roadways are not really interested in the matter, and regard with some justification any money above that necessary to produce sufficiently poor lighting to permit pedestrians to grope their way about as a burden they should not be asked to carry; fortunately, there are definite signs that this state of affairs is being remedied, and (b) With the tremendous increase of both goods and passenger motor traffic our roads are now being used during the hours of darkness to an extent formerly undreamed of, and anything that can be done to help this traffic to avoid accidents is doubly welcome. Many local authorities now recognise the importance of good roadway-lighting in the avoidance of traffic accidents, but one frequently reads in reports of coroners' courts that better lighting is necessary along roads in which fatal accidents have occurred. Such recommendations are usually taken seriously now that the country as a whole has been made conscious of the terrible toll of the road in killed and injured, but in such cases they indicate that the local authority concerned is not free from blame, and that it had not foreseen that the modern increased use of the roads during night time required far better lighting than sufficed for pedestrian and somewhat infrequent and always slow horse-drawn traffic of thirty years ago.

With the need for very much improved street-lighting, illuminating engineers have kept pace—or even set the pace—both on the theoretical and technical and on the practical sides. During the last few years the technical advances made in street-lighting matters have been little short of revolutionary, and it is with a view to providing a neutral platform on which these technical matters can be discussed that the Council of this Society has decided to set up a Public Lighting Section. In order to begin work on this problem anew, it is necessary to get a proper perspective of our present position, both in relation to past experience and to future tendencies. To assist in the former, an attempt has been made to collect together some of the principal theoretical ideas and technical considerations that have helped to give form to the modern ideas of what street-lighting should be and what it should do. To help to indicate possible future tendencies, a few experiments dealing with one aspect of the street-lighting problem are described later.

Uniform Illumination.

Street- and road-lighting became a serious technical matter with the introduction of light controlling and redirecting equipment, in the development of which it is pleasing to acknowledge the pioneer work of a former President of this Society, Mr. A. P. Trotter[1]. As far back as 1884 Mr. Trotter gave details of a scheme of light control and distribution suitable for road-lighting. In America wide angle symmetrical refractors were made (not marketed) prior to 1910, to be followed by directional or asymmetrical refractors of various types in 1923 [2]. Since that time, many types of directional equipment using reflectors and refractors have been used. The avowed aim of the early workers in this field was to produce as near as was commercially possible uniform illumination along the roadway, a diversity factor of less than 10 to 1 being regarded as reasonably good, while with non-directing equipment and the relatively wide spacing then adopted the diversity ratio often reached 40 to 1. In the days before tarmacadam roads, highly polished by the tyres of motor traffic, such an aim was excellent, as the road surfaces were generally much lighter in colour and had much more diffusely reflecting surfaces than modern roads. In cases where we still have such diffuse reflecting road surfaces, as for example, relatively rough concrete, or granite sets, approximately uniform illumination along the roadway provides very satisfactory results both from the point of view of the pedestrian who wants to see things near at hand, using generally direct vision, and also from the point of view of the motorist who, using silhouette vision, wants to see things clearly outlined some distance ahead (Fig. 1).

The early workers in this field recognised more clearly than some more recent exponents that the directional lighting of roads needed care, since the indiscriminate projection of intense beams of light along a road was liable to give rise to uncomfortable glare unless the angle of elevation of the beam was carefully controlled. In well-designed directional lighting fittings, the main beam was generally projected at about 15° below the horizontal—at this angle glare was not serious unless an excessively intense beam was projected or unless the mounting height was too low [3]. The adoption of this angle of beam permitted such directional fittings to be used satisfactorily for spacing-height ratios up to 8. Attempts to reduce the cost of installation and maintenance, by increasing the spacing-height ratio, either by increasing the spacing or by decreasing the mounting height, involved the use of higher beam angles, with a consequent increase of glare. On general principles this should not be encouraged.

Road Surface Brightness.

The widespread use in the making of modern roads of such materials as tarmacadam and asphalt, which take a fairly good polish after being subjected to heavy motor traffic for some time, has led to the resurrection of theories of street lighting based on

Fig. 1. Street Lighting arranged on a "Uniform Illumination" basis. Diversity Ratio about 4 to 1. The surface consists of granite sets.

road surface brightness [4]. Here again the pioneer workers regarded this matter from all points of view, and recognised its limitations much more clearly than some more recent exponents of this theory.

In the transactions of the American Illuminating Engineering Society for October, 1910, there are two papers dealing with this subject, one entitled "The Silhouetting Effect" [5] and the other "Some neglected considerations pertaining to street illumination" [6]. The same subject was again raised at the Bellagio meeting of the I.C.I. in 1927 by Peri [7], but by far the most complete statement of the case among these early papers is to be found in a paper entitled "Brightness of Street Surfaces—Effectiveness in Street Lighting," presented to the 1928 meeting of the I.C.I. in America by Preston S. Millar [8]. In this paper Millar gave the reflection polar curves of four typical road surfaces. He measured the brightness of road surfaces, using a modified visual photometer tilted 2° below the horizontal, and also explored the brightness variations over road surfaces. He further emphasised that the illumination on a road surface and the brightness distribution did not follow one another.

In spite of the undoubted assistance given by a bright background in producing a clear silhouette effect, Millar admitted that from the point of view of street lighting the following circumstances gave rise to difficulties which could not be overlooked:—

I. Different types of road surfaces produced very different brightness effects.
II. Wet road surfaces were of frequent occurrence and produced entirely different results from dry surfaces.
III. Glare needed to be very carefully controlled.

The paper also included practical hints on how to obtain the best surface brightness results, and stressed the importance of correct lamp placement, recommending two rows, or on wide streets three rows of lamps, placed well out over the roadway. In a later paper [9] prepared by the American Street Lighting Committee and presented to this same meeting (1928 I.C.I.) this point was further elaborated, and the placing of lamps on the outsides of curves was recommended.

In all this pioneer work Millar recognised that road surface brightness was only one aspect of the street lighting problem and that its pursuit entailed certain disadvantages. As a matter of fact he took out a patent in 1929 [10] for a unit which embodied a shield to prevent light being emitted from a street lighting fitting along the roadway, at what might be called "glare" angles, in spite of the fact that such light was highly effective in producing high brightness of the road surface.

Those who were present at the meeting of the street lighting section of the I.C.I. in 1935 will remember that Peri has also recognised that the pursuit of high surface brightness is not without accompanying disadvantages, and has ceased to recommend that ideal in street lighting.

During recent years the importance of high and even road surface brightness has been emphasised in this country and in some quarters almost elevated to a creed, apparently being regarded as the one and only characteristic of a street lighting installation that is worthy of attention. Some of the newer protagonists do not seem to recognise the difficulties to which it leads as clearly as the earlier workers on

this subject. For instance, the importance of glare appears to have been overlooked, though it is surely obvious that strong beams of light impinging on the eye only a few degrees from the normal line of sight must result in an impairment of vision. Then again, the statement is frequently heard that a polar curve of a particular type is necessary to produce high and uniform road surface brightness. Yet it is generally agreed that the brightness of a road surface is more a function of the nature of the surface than of the precise form (as distinct from the general form) of the polar curve of the lighting fitting, and also that brightness distribution on a road surface can be completely altered by a simple repair of the surface or even by a shower of rain, such change in brightness distribution naturally occurring without any change in the shape of the polar curve of the fitting used on the road. Confirmation is afforded by the common experience that certain lighting fittings may give very uniform brightness results on certain roads, and yet in neighbouring installations in which identical fittings are used (having, of course, the same polar curves, and mounted at the same height and spacing), the results may be far from uniform.

Despite this criticism of the somewhat extreme modern version of the road surface brightness theory, it must be agreed that road surface brightness is a very important factor in assisting silhouette vision and producing brightness contrasts by which obstructions are seen on roadways, but the theory must be applied in practice judiciously and with a full recognition of other factors involved in good street lighting, and also with an appreciation of the varying needs of the different classes of road users. In towns and populous areas where pedestrian traffic is heavy and where the road surface only forms a relatively small proportion of the backgrounds against which motor drivers see objects [11], it seems obvious that a different form of lighting could be adopted with advantage from that which is used for the lighting of motor roads. In the former, uniformity of illumination is of greater importance, while in the latter it is subservient to satisfactory road surface brightness.

Uniform Glare.

An extension of the road surface brightness theory has recently been put forward [12] in which the question of glare has not been neglected, instead it has been raised to a matter of primary importance, but in a rather unusual way. It is assumed in the first place that in street lighting glare is unavoidable, and it is then argued that fittings should be so designed as to produce a constant degree of glare, no matter at what angle they are viewed. On the basis of the equation:

$$\text{Glare} = \frac{\text{Candlepower at any angle below the horizontal}}{H^2\,\theta^{3/2}\,\text{cosec}^{\,2}\,\theta}$$

H being the height of the source above the eye, a polar curve is calculated which corresponds to a uniform glare at every angle of elevation. This curve is reproduced in Fig. 2.

While not admitting the accuracy of the postulates on which this theory is built, nor of the arguments

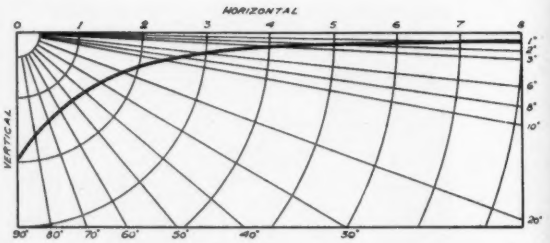


Fig. 2. Curve illustrating conditions to secure uniform glare.

used in its development, there is probably something in the practical conclusions that accompany its presentation. It is also probable that these practical conclusions do not depend in any way on the theory which they are supposed to illustrate, and that they are capable of explanation along quite different and much simpler lines.

Absolutely No Glare.

Now, to pass right to the other extreme; there are many people to whom any suggestion of glare in street lighting is abhorrent above everything else, and absolute freedom from glare is, in their opinion, the first and foremost essential. This attitude is much stronger on the Continent than it is here, and as a result, street lighting systems embodying opaque reflectors, with a positive cut-off below the horizontal, or a virtual cut-off using a band of strongly diffusing glass, are popular in several Continental countries. Whether the reflectors used in these systems are symmetrical or asymmetrical in character, they practically always throw their reflected light down on to the road surface at much steeper angles than is usual here. In turn, this method necessitates a smaller spacing-height ratio—which is frequently in the neighbourhood of 4 to 1, and is attained by both higher mounting heights and closer spacing than is common here. In this way it is possible to get quite satisfactory results, and it must be admitted that along their well-lighted roads, although the general appearance is not so impressive as that of some of our roads, it is possible to see in comfort.

It is obvious, however, that with such a small spacing-height ratio, the cost of installation must be high and such as can only be justified on the more important roads. When greater spacing-height ratios, such as 6 or 8 to 1 are used, the results are much less satisfactory, and that for two reasons: (a) reflectors become much less efficient when the angle of the main beam is raised much above 60° or 65° [13], which angles correspond to spacing-height ratios of from 4 to 5; and (b) the occurrence of the well-known "spotty" effect that is produced when units are used at wider spacings than their light distribution calls for. In such cases the lighting being characterised by what we know as "pools of darkness" is definitely depressing and unsatisfactory.

In spite of the necessity of using small spacing-

height ratios, when opaque reflectors are used, some indirect support for such a scheme has recently been put forward in America by Reid and Chanon [14], who suggest that street lighting equipment should have a positive cut-off at 10° below the horizontal. In arriving at this conclusion they were working with a spacing-height ratio of 5 to 1.

It is noteworthy that generally speaking people who hold one or other of these views regarding street lighting do so with a sincerity that leads them to believe that their particular aim is the one thing in street lighting that matters, and it is significant that each one of the ideals that thus comes to be looked upon almost as a religion is nothing more than the one aspect of a many sided problem.

Real Aim of Street Lighting.

The aim of street lighting is not to produce uniform illumination along the roadway, nor to produce uniform and high surface brightness, nor to eliminate glare, nor to produce a constant degree of glare, but simply to enable road users of whatever class they belong to see clearly whatever they need to see, more particularly to see obstacles and circumstances that may lead to danger. This may seem an obvious fact, but it does seem necessary to emphasise it and to impress on the specialist that there is something in the points of view that are held by other people regarding the means by which good street lighting may be achieved. In this connection, it is well to emphasise that the pedestrian must be considered as well as the motorist, and that, ordinarily speaking, the pedestrian needs to see people and things generally at a relatively close range, so that the brightness of the road a quarter of a mile away is of no interest to him. It must also be remembered that the motorist needs to see clearly and quickly in the near neighbourhood of his car, for many more accidents occur as the result of pedestrians stepping off pavements immediately in front of a car, or as the result of cyclists coming out of side turnings just as a car reaches them, than are due to the fact that the motorist was not able to see something on the road a quarter of a mile away.

Experimental Work.

If an attempt is made to determine in an experimental manner what constitutes good street lighting, innumerable difficulties crop up. These difficulties divide themselves into two general classes. The first is psychological—for what is good street lighting is a matter of opinion, and it is therefore difficult to get agreement. Even if agreement be obtained, it is still more difficult to get a numerical evaluation of the goodness or otherwise of an installation.

The second class of difficulties, which is physical in character, arises from the enormous number of variables that enter into street lighting practice—to name just a few that vary over wide ranges—mounting height—spacing of units—lumen output of sources, types of light source—light distribution of fittings—presence or otherwise of positive or reasonably effective cut-off—nature of road surface, and its condition.

To get a precise knowledge of the effect of varying any one of these factors it is necessary in a series of tests to maintain all the other factors as constant as possible. Apart from the nature and condition of the road surface over which illuminating engineers have no control whatever, the one factor in the above list which is most likely to yield valuable results from the street lighting point of view is that concerning the light distribution given by fittings. To permit work along these lines to be carried out without interference from traffic and with an approach towards practical street lighting conditions, a model roadway on a fifth scale has been arranged on a flat roof which has a very dark grey surface (reflection factor=8 per cent.), similar to that of an unpolished tarmac road. The length of the model road is 100 feet, and by means of a large plate glass mirror at one end it is rendered equivalent to an actual road length of 333 yards.

The width of the roadway itself is 7 feet, and the two footpaths, painted a dark stone colour, are each 1 foot wide; these correspond to a carriageway of 35 feet and paths 5 feet in width. Five fixed crossbars are arranged 6 feet high and 25 feet apart; from these lamps can be suspended at any position over the width of the roadway. Three types of installation, centre mounting, staggered overhung (1 foot, corresponding to 5 feet on road) and staggered kerb mounting, were investigated with each fitting, except those that were specially designed for one type only.

In the area between the third and fourth lamps 15 regularly placed spots were painted on the roadway, arranged as indicated in Fig. 3.

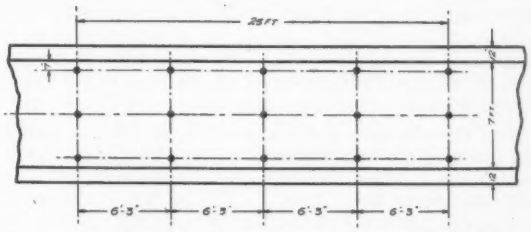


Fig. 3. Plan of Model Street, showing test positions.

These spots were used in the taking of certain measurements and observations to be mentioned later. The observations were all made from a fixed observation station 2 feet behind the first lamp and 1 foot 9 inches from the nearside kerb. The observations were made at an eye level of 1 foot from the road surface, corresponding to an eye level of 5 feet on a full scale roadway. The distance of the observed area from the observation station was from 52 feet to 77 feet, corresponding to a full scale distance of from 87 to 128 yards.

The measurements and observations made were as follows:—

A. In each test the following preliminary details were recorded: type and size of lamp, type of fitting, maximum beam angle, cut-off (if any), mounting height, spacing-height ratio, type of installation, surface and atmospheric conditions. Throughout the present tests 40-watt coiled-coil, clear lamps were used, with their filaments 4 feet 2½ inches above the

road surface, thus giving a fixed spacing-height ratio of 6 to 1.

B. Illumination readings were taken using an autophotometer at each of the fifteen marked places and at the two B.S.S. test points. From these readings isolux diagrams have been prepared.

C. Surface brightness readings were taken, using a modified lumeter in some preliminary tests, but owing to the wide variations in readings that were obtained for the same installations, the only variant being the condition of the road surface, they appeared to be leading nowhere, and were discontinued.

D. An attempt to get a numerical measure of the visibility of objects at different places on the roadway was made, using for this purpose the fifteen marked spots situated between the third and fourth lamps. The readings were taken from the fixed observation station in the following way. A small electric motor had fixed to its shaft a circular brass disc six inches diameter: the disc was painted matt grey (reflection factor 12 per cent.), and had a piece one inch square cut away in the form of a square recess from the periphery: on the motor shaft behind the disc was a 12-sided brass collar, against which rested a flat steel spring, so arranged as to arrest the spinning of the disc and cause it to stop in a position corresponding to any one of the 12-hour locations on a clock face.

The motor was placed in turn on each of the fifteen spots, with the disc facing the observation station, an assistant near the disc operating a switch caused it to rotate for a moment; as soon as it stopped, the observer, with eyes kept at 12 inches from the road surface, called out the "hour" at which the recess had stopped, if he could see it. Ten attempts were made at each of the fifteen fixed places, and the number correct in each case was recorded.

For presentation, these readings have been grouped into three sets corresponding to the three lines of dots on the roadway, one giving the number of correct readings along the "near" side of the roadway, the second giving the figures for the middle of the roadway, and the third set for the "off"-side of the roadway. The three sets are then taken together and the visibility over the whole of the roadway expressed as a percentage figure.

E. An attempt was made to get a rough estimate of glare, and also to see to what extent this was relieved by road surface brightness, with a view to seeing what relation these features had to the percentage visibility just discussed. This was done by switching off number one lamp, which was only 2 feet in front of the observation station. The light then reaching the eyes at the standard level came (a) from the remaining lamps, which were all within 6½° of the horizontal line of sight, and (b) by reflection from the roadway, which was necessarily below the horizontal line of sight. Within this angle of 6½° above the horizontal it is probably safe to assume for our present purposes that the glare from the lamps was proportional to the direct light intensity falling on the eye. Acting in the opposite sense and tending to mitigate the glare effect, the light reflected from the road surface would help to raise the visibility. These two opposing factors were separated and measured as follows: the eye was replaced by the cells of a very sensitive autophotometer, the sensitive face of the cells being vertical and facing the illuminated roadway (the first lamp being off). A reading of the total light falling on the cells was taken, and then the light reflected to the cells from the road surface was blocked off, without intercepting any of the light coming direct from the lamps, by two wood screens drawn across the roadway, thus giving a reading on the autophotometer of the direct light from the lamps only. By difference, the light reflected to the cells from the road surface was obtained. These two figures have been recorded, together with the ratio of the direct to the reflected light—which may be looked upon as a kind of glare index. This index is misleading when applied to wet road surfaces, as then the direct reflection of the sources increases, thus reducing the index figure, whereas the actual glare effect on the eyes is considerably increased.

F. A photograph of each installation was taken from the observation station, with the centre of the lens of the camera at one foot from the road surface. In each case an exposure of 30 seconds at *f*.11 was given; the conditions of exposure and development were kept uniform throughout.

G. Finally, the polar curve of the fitting on test was determined. Since the filament of the 40-watt coiled-coil lamp is so unsymmetrical, it was necessary to take polar curves in the plane of the filament and at right angles to it, thus showing the minimum and maximum that might be expected from any fitting in any particular direction.

Results.

The tests reported include bare lamps and the same lamps with vitreous enamel reflectors, giving varying degrees of cut-off, with symmetrical silvered glass reflectors, these same silvered glass reflectors with asymmetrical refractors, and finally with symmetrical and 180° and 150° asymmetrical two-piece dome refractors.

The essential data from a number of these tests are set out in the Appendix, but for the sake of convenience they are summarised very briefly in Table I.

Although as yet it is impossible to draw any definite and general conclusions, it does appear possible to detect some interesting indications. It will be remembered that Reid and Chanon recommend a positive cut-off at 10° below the horizontal, but the tests with the vitreous enamel reflector giving different degrees of cut-off do not confirm this conclusion.

Considering the series of readings using the reflector arranged to give a cut-off above the horizontal and those with the reflector giving a 10° cut-off, it will be seen that the test-point illuminations and the diversity ratios are of the same order, and in spite of the fact that the glare index is much lower with the 10° cut-off, the visibilities in the corresponding types of installations are almost identical. Though there is no general improvement in visibility, there does, however, appear to be an advantage lying with the cut-off fitting in so far as it permits of some degree of visibility along the off-side of the roadway,

TABLE I. Essential Data derived from Tests

TABLE I. Essential Data derived from Tests

Fitting	Bare Lamp			V.E. Reflector.			V.E. Reflector			V.E. Reflector			Silvered Glass Reflector.		
Type of Install'n and Test No. ...	C. 2	S.o.h. 3	S.K. 4	C. 5	S.o.h. 6	S.K. 7	C. 8	S.o.h. 9	S.K. 10	C. 11	S.o.h. 12	S.K. 13	C. 14	S.o.h 15	S.K. 16
Angle of Max. Beam	—	—	—	0°	0°	0°	0°	0°	0°	0°	0°	0°	72°	72°	72°
Cut-off	—	—	—	—	—	—	—5°	—5°	—5°	—10°	—10°	—10°	—8°	—8°	—8°
Test Point ...	0.110	0.110	0.110	0.130	0.120	0.118	0.13	0.122	0.107	0.110	0.112	0.108	0.34	0.20	0.23
Ill'ns. (f.c.) ...	0.105	0.108	0.108	0.133	0.119	0.122	0.12	0.120	0.106	0.115	0.115	0.110	0.36	0.22	0.28
Diversity Ratio ...	21	20	20	34	37	38	33	33	38	24	23	24	7.2	11	10
Glare Index															
Direct light from lamps (f.c.)...	0.064	0.070	0.075	0.068	0.070	0.068	0.040	0.043	0.032	0.006	0.007	0.006	0.007	0.005	0.005
Light reflected from road (f.c.) ...	0.0015	0.017	0.011	0.002	0.002	0.007	0.004	0.0025	0.002	0.001	0.001	0.0015	0.0025	0.002	0.002
Direct/Reflected ...	43	4.1	6.8	34	35	9.7	10	17	16	6	7	4	2.8	2.5	2.5
Visibility															
Near-side (50) ...	26	29	32	23	33	29	9	12	20	18	33	26	23	30	14
Centre (50) ...	45	50	42	42	42	39	43	33	20	45	32	29	46	26	22
Off-side (50) ...	0	2	4	0	0	0	0	9	26 (some d. vision)	6	10 (d. vision)	15 (10 by d. vision)	11	17	22
Total %	47	54	52	44	50	45	35	36	44	46	50	46	53	49	39
Remarks		Surface wet-drying	Surface wet-drying			Few wet patches	Few wet patches	Few practically dry patches	Few practically dry patches				Brightness balance at 3 test locations, visibility appeared better than indicated by figures	Brightness balance at four test positions	Two spots on balance point and two gave direct vision

Fitting	Sil. Gl. Refl. & Refr. Dish		Symm. 2-piece dome refractor			Asym. ax. 2-p. dome refr.			Asym. 150° 2-p. dome refr.			Asym. 150° 2-p. dome refr.		
Type of Install'n and Test No. ...	S.o.h. 17	S.K. 18	C. 19	C. 20	C. 21	C. 22	C. 23	C. 24	S.o.h. 25	S.o.h. 26	S.o.h. 27	S.K. 28	S.K. 29	S.K. 30
Angle of Max. Beam	72°	72°	70°	75°	80°	70°	75°	80°	70°	75°	80°	70°	75°	80°
Cut-off	Virtual —10°	Virtual —10°	Virtual —10°	Virtual —5°	Virtual along Horizontal	Virtual —10°	Virtual —5°	Virtual Horizontal	Virtual —10°	Virtual —5°	Virtual Horizontal	Virtual —10°	Virtual —5°	Virtual Horizontal
Test Point ...	0.191	0.16	0.13	0.228	0.173	0.19	0.248	0.181	0.32	0.255	0.179	0.254	0.215	0.165
Ill'ns. (f.c.) ...	0.259	0.235	0.175	0.235	0.190	0.27	0.28	0.189	0.22	0.195	0.158	0.204	0.200	0.154
Diversity Ratio ...	7	8	26	15	19	16	12	17	13	14	18	14	13.5	17
Glare Index														
Direct light from lamps (f.c.)...	0.0495	0.040	0.030	0.0775	0.100	0.057	0.104	0.200	0.041	0.0565	0.069	0.045	0.051	0.070
Light reflected from road (f.c.) ...	0.0025	0.003	0.002	0.0025	0.002	0.0025	0.0035	0.006	0.0035	0.003	0.0025	0.0025	0.003	0.003
Direct/Reflected ...	20	13	15	31	50	23	30	33	12	19	28	18	17	23
Visibility														
Near-side (50) ...	31	31	41	47	43	37	50	43	39	40	35	43	45	35
Centre (50) ...	40	33	49	47	45	50	49	49	41	45	48	38	40	45
Off-side (50) ...	10	18	13	16	5	3	9	7	9	10	10	10	9	10
Total %	54	55	69	73	62	60	72	66	60	64	61	60	61	60
Remarks	Brightness balance at four test positions	Brightness balance at three test positions	Brightness balance at one test position		Much harder on the eyes than the 70° or 75° beams	Brightness balance at one test position			Brightness balance at two test positions			Brightness balance at two test positions		

whereas with the reflector without any cut-off it was impossible to obtain a single correct reading at any one of the five test locations down that side of the roadway.

TEST NUMBERS	5	6	7	11	12	13
INSTALLATION	C	Son	SK	C	Son	SK
CUT OFF	0	0	0	-10°	-10°	-10°
GLARE INDEX	34	35	9·7*	6	7	4
VISIBILITY						
NEAR SIDE	23	33	29	18	33	26
MIDDLE	40	42	39	45	32	29
OFF SIDE	0	0	0	6	10	15
TOTAL PERCENTAGE	44	50	45	46	50	46

* WET PATCHES ON ROAD SURFACE

Fig. 4. Effect of 10° cut-off.

It is interesting to compare the results obtained with the vitreous enamel reflector and the silvered-glass reflector, since both have approximately the same angle of cut-off (−10° and −8° respectively), but have very different light distributions, the enamel reflector, of course, giving the maximum intensity directly downwards, whilst the silvered reflector gave a maximum intensity at 72° from the vertical. The silvered reflector naturally gave much higher test-point readings and much more even lighting, as indicated by the lower diversity ratios; it also gave still lower glare indices. Distinctly higher visibility values might therefore be expected, but they were not recorded. This was due to the fact that in quite a number of test locations the brightness of the disc was practically identical with that of the background. In some positions the disc, being brighter than the roadway, was seen by direct vision. If the disc had been a darker grey, the visibility figures for the silvered reflector installations would have been better.

TEST NUMBERS	11	12	13	14	15	16
INSTALLATION	C	Son	SK	C	Son	SK
ANGLE OF MAX BEAM	0	0	0	72	72	72
ANGLE OF CUT OFF	-10°	-10°	-10°	-8°	-8°	-8°
AVERAGE TEST PT ILLM.	·112	·113	·119	·35	·21	·25
DIVERSITY RATIO	24	23	24	7	11	10
GLARE INDEX	6	7	4	2·8	2·5	2·5
PER CENT VISIBILITY	46	50	46	55	49	39

Fig. 5. Effect of Light Distribution.

There are also interesting indications to be drawn from the data recorded under the test numbers 19 to 30. These four sets of tests refer to two-piece dome refractors of differing types, each mounted in accordance with the type of light distribution it produced. In each of the four cases three separate tests were made, with the main beams from the refractors directed at different angles from the vertical, viz., 70°, 75°, and 80°. The results obtained are consistent throughout the whole series. It will be seen, in general, that the highest test-point illumination and the lowest diversity ratios are obtained when the refractors are arranged to emit their main beams at 75° from the vertical. As would be expected, as

TEST NUMBERS	19	20	21	22	23	24	25	26	27
ANGLE OF MAX BEAM	70	75	80	70	75	80	70	75	80
AVERAGE TEST PT ILLM	·15	·23	·18	·23	·27	·18	·27	·23	·17
DIVERSITY RATIO	26	15	19	16	12	17	13	14	18
GLARE INDEX	15	31	50	23	30	33	12	19	28
PER CENT VISIBILITY	69	73	62	60	72	66	60	64	61

Fig 6. Effect of Beam Angle.

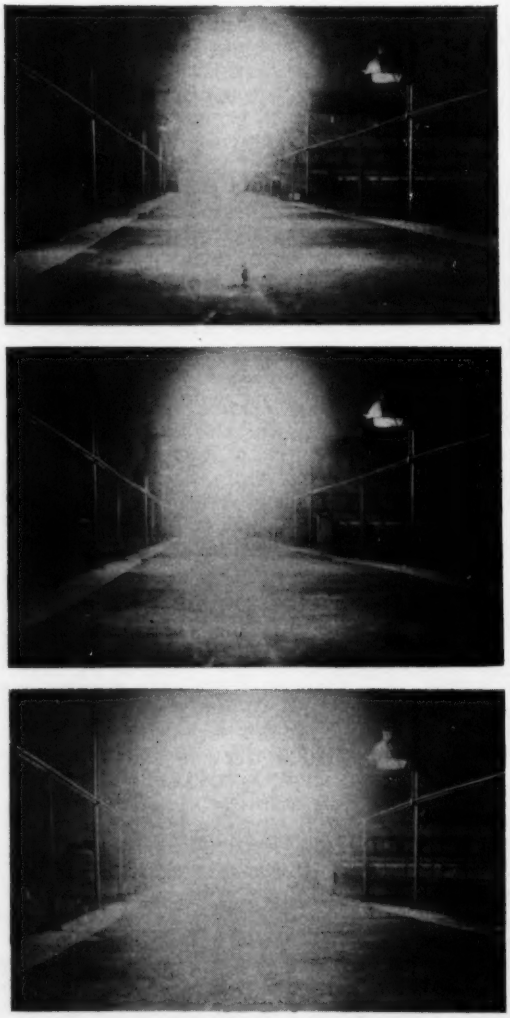


Fig. 7. Comparative glare from fittings, with main beams at 70°, 75°, and 80°.

the angle of the maximum beam is raised, the glare index is increased. At the same time one would expect an increased road surface brightness, and, if visibility depended only on the contrast between the brightness of the object and the brightness of the road surface, an increased visibility figure would be expected. This expectation is realised on passing from 70° beams to 75° beams, but on passing to 80° beams the visibility figures fall again. There can be no doubt that this fall is due to the increased glare that is experienced with the 80° beams, for in the cases in which the glare index rises most the percentage visibility shows the largest reduction.

Incidentally, it is interesting to note that the highest visibility figures were obtained with the symmetrical and the axial dome refractors centrally mounted, although this system of mounting is not looked upon with favour in certain quarters.

One further point of interest appears to emerge from these figures, and that is that when the main beams from the fittings are emitted at or about 70° from the vertical, there is a marked tendency to get a brightness balance between the disc and the background, thus making it impossible to pick out the position of the recess in the disc. This brightness balance is, no doubt, due to the fact that with beams emitted at this angle the surface brightness of the roadway is not sufficiently high to give clear visibility. The ideal angle at which beams should be emitted in order to give the best compromise between road surface brightness on the one hand and glare on the other hand, appears to be in the neighbourhood of 75.°

It must once again be emphasised that the results recorded above do not give a complete survey of even this one aspect of the street lighting problem, and that definite conclusions cannot be deduced from the data presented with any degree of certainty. It is felt, however, that the recording of these observations, as distinct from opinions based on unrecorded data, may be of use to those interested in the street lighting problem.

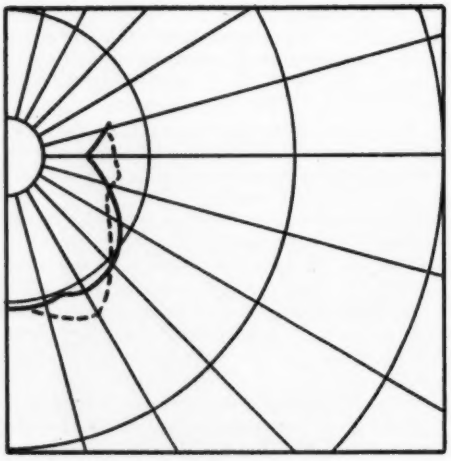
In conclusion, the author wishes to record his thanks to Messrs. Stroud, Cole, and Hobbs, who have spent many cold nights assisting him in taking the observations and readings embodied in this paper.

(1) A. P. Trotter. Proc. Inst.C.E., 1883-4, Paper No. 1,964.
(2) Brit. Patent, 217,539/1924.
(3) See Cady and Dates (Wiley and Sons, 1925), 422.
(4) J. M. Waldram, Ill. Eng., 1934. Oct., 305, and Nov., 339.
(5) P. S. Millar. Tr. Am.I.E.S., 1910, 653.
(6) P. S. Millar. Tr. Am.I.E.S., 1910.
(7) G. Peri, I.C.I., 1927. L'Ellettrotecnica, 1928, xv., 263.
(8) P. S. Millar, Trans. Am.I.E.S., 1928, xxiii., 1,051.
(9) Amer. Street Lighting Committee, Proc.I.C.I., 1928, 103.
(10) U.S.A. Pat., 1,738,383/1929.
(11) F. C. Smith and K. F. Sawyer, Ill. Eng., 1935, xxviii., 365.
(12) D. J. Sandeman, Public Lighting, June, 1936, 46.
(13) T. W. Rolph, Am.I.E.S., 1937, xxxii., 161.
(14) Reid and Chanon, Am.I.E.S., 1936, xxxi., 119.

APPENDIX. Typical Data derived from Tests

2

FITTING — NONE
LAMP — 40 WATT - CC - CLEAR
ANGLE OF MAX BEAM — —
CUT OFF — ABOVE HORIZONTAL
SPACING HEIGHT RATIO — 6 TO 1
TYPE OF INSTALLATION — CENTRAL
SURFACE CONDITION — DRY - VERY SLIGHT HAZE



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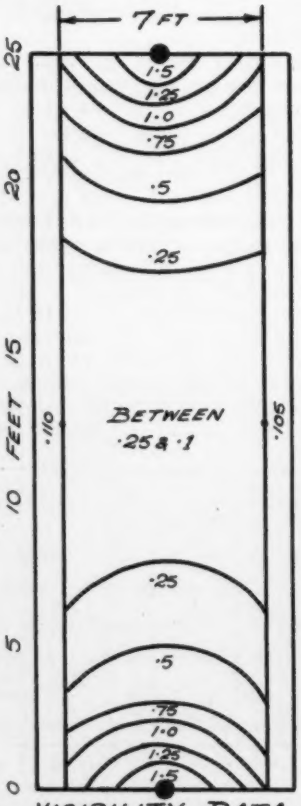
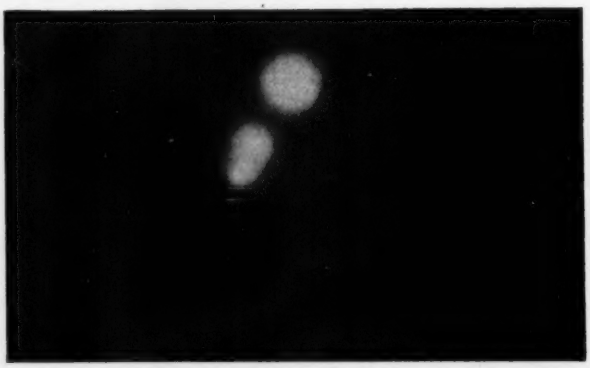




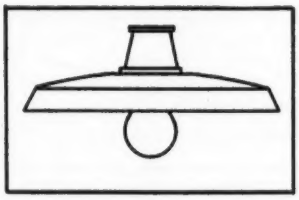
VISIBILITY DATA
NEAR SIDE - 26
MIDDLE - 45
OFF SIDE - 0
TOTAL 71.
" PERCENTAGE 47.

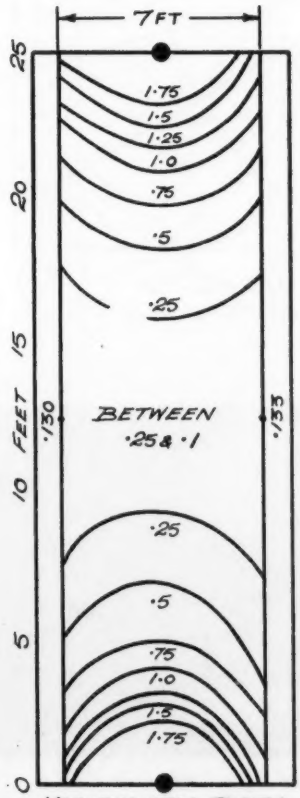
HORIZONTAL LIGHT INTENSITY AT EYE LEVEL

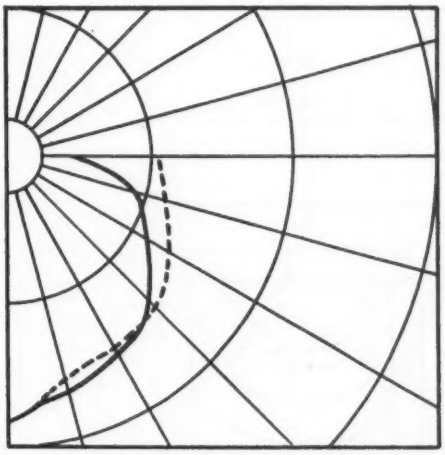
DIRECT FROM FITTINGS 0·064
REFLECTED FROM ROAD 0·0015
GLARE INDEX 43

5

FITTING	LAMP WITH V.E. REFLECTOR
LAMP	40 WATT-CC - CLEAR
ANGLE OF MAX BEAM	—
CUT OFF	ABOVE HORIZONTAL
SPACING HEIGHT RATIO	6 TO 1
TYPE OF INSTALLATION	CENTRAL
SURFACE CONDITION	DRY — THIN HAZE







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- - - ACROSS FIL

VISIBILITY DATA

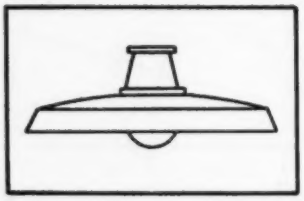
NEAR SIDE	23
MIDDLE	42
OFF SIDE	0
TOTAL	65
" PERCENTAGE	44

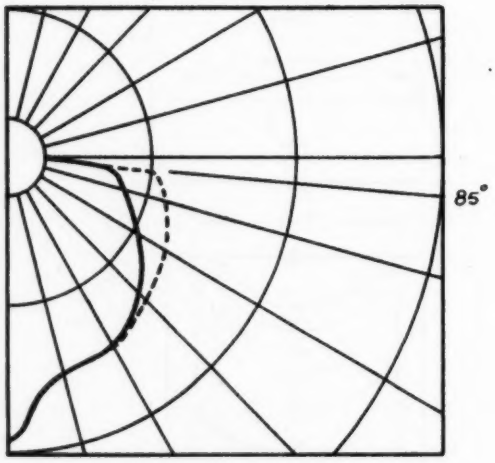
HORIZONTAL LIGHT INTENSITY AT EYE LEVEL

DIRECT FROM FITTINGS	0·068
REFLECTED FROM ROAD	0·002
GLARE INDEX	34

8

FITTING — LAMP WITH V.E. REFLECTOR
LAMP — 40 WATT-CC-CLEAR
ANGLE OF MAX BEAM — —
CUT OFF — MINUS 5°
SPACING HEIGHT RATIO — 6 TO 1
TYPE OF INSTALLATION — CENTRAL
SURFACE CONDITION — DRY—EXCEPTING FEW WET PATCHES





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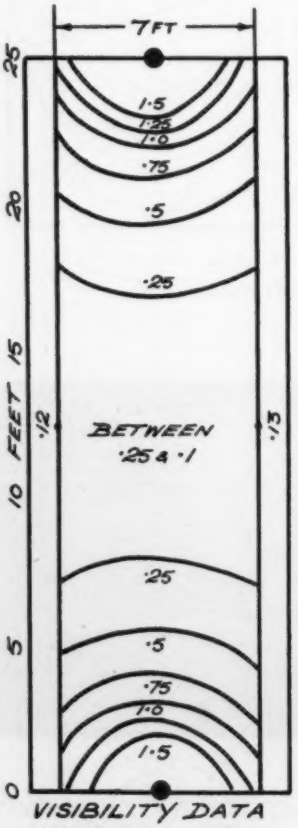


VISIBILITY DATA

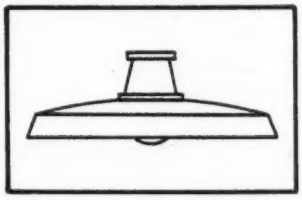
NEAR SIDE	9
MIDDLE	43
OFF SIDE	0
TOTAL	52
" PERCENTAGE	35

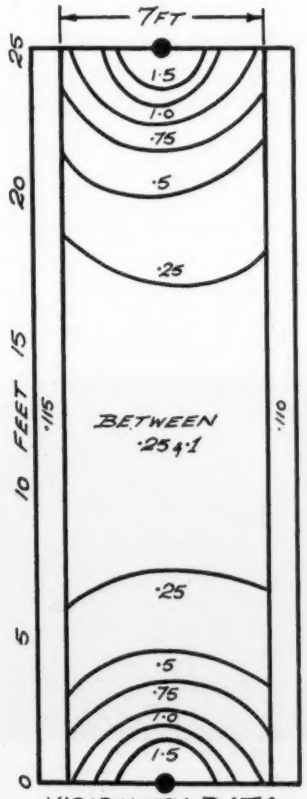
HORIZONTAL LIGHT INTENSITY AT EYE LEVEL

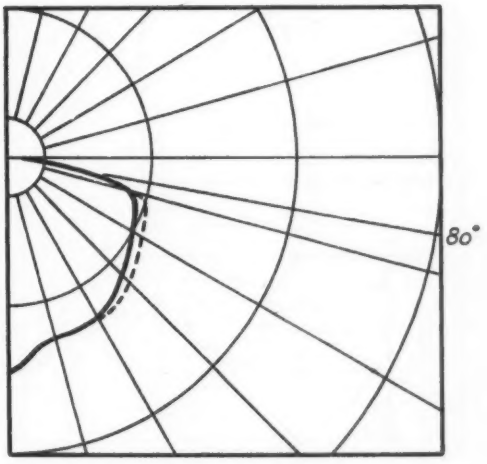
DIRECT FROM FITTINGS	0·040
REFLECTED FROM ROAD	0·004
GLARE INDEX	10

11

FITTING	LAMP WITH V.E. REFLECTOR
LAMP	40 WATT - CC - CLEAR
ANGLE OF MAX BEAM	—
CUT OFF	MINUS 10°
SPACING HEIGHT RATIO	6 TO 1
TYPE OF INSTALLATION	CENTRAL
SURFACE CONDITION	DRY







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VISIBILITY DATA

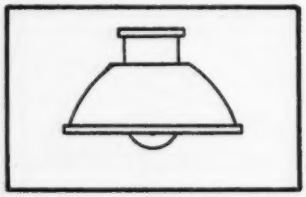
NEAR SIDE	18
MIDDLE	45
OFF SIDE	6
TOTAL	69
" PERCENTAGE	46

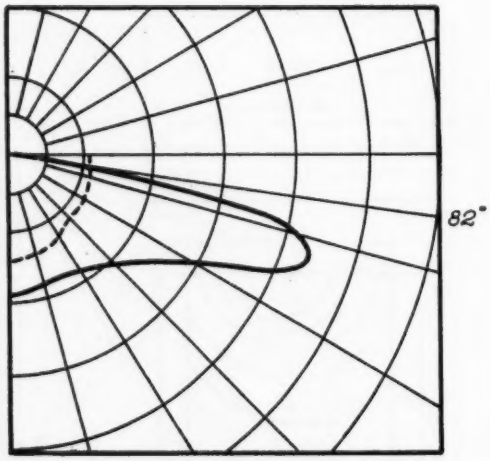
HORIZONTAL LIGHT INTENSITY AT EYE LEVEL

DIRECT FROM FITTINGS	0·006
REFLECTED FROM ROAD	0·001
GLARE INDEX	6

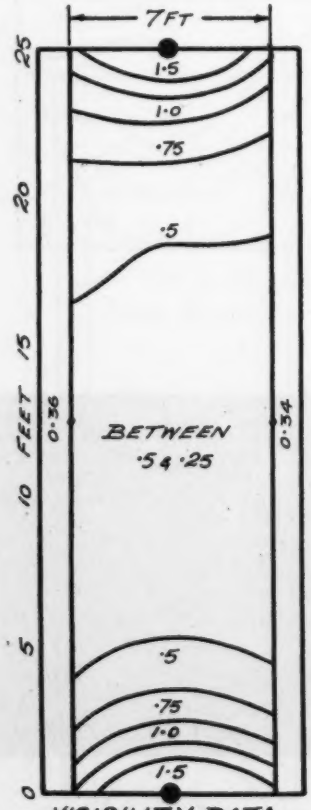
14

FITTING — LAMP WITH SILVERED REFLECTOR
LAMP — 40 WATT - CC - CLEAR
ANGLE OF MAX BEAM — 73°
CUT OFF — LAMP AT 82° - REFLECTOR EDGE 90°
SPACING HEIGHT RATIO — 6 TO 1
TYPE OF INSTALLATION — CENTRAL
SURFACE CONDITION — DRY





— FITTING
--- BARE LAMP



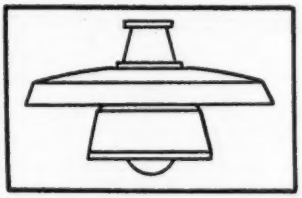
VISIBILITY DATA
NEAR SIDE 23
MIDDLE 46
OFFSIDE 11
TOTAL 80.
" PERCENTAGE 53.

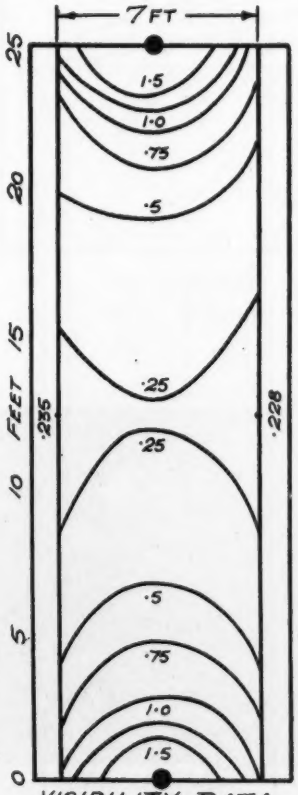
HORIZONTAL LIGHT INTENSITY
AT EYE LEVEL

DIRECT FROM FITTINGS	0·007
REFLECTED FROM ROAD	0·0025
GLARE INDEX	2·8

20

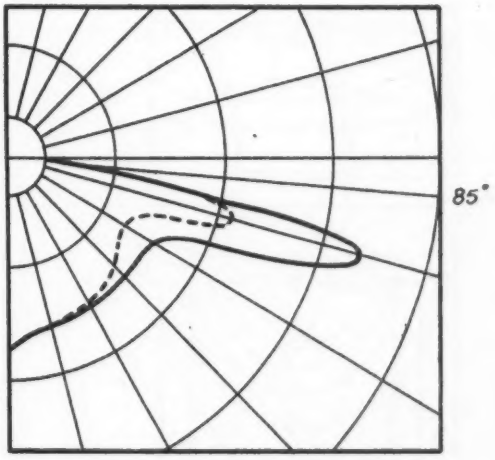
FITTING	TWO-PIECE SYM-DOME WITH V.E. REFL
LAMP	40 WATT - CC - CLEAR
ANGLE OF MAX BEAM	75°
CUT OFF	VIRTUAL - MINUS 5°
SPACING HEIGHT RATIO	6 TO 1
TYPE OF INSTALLATION	CENTRAL
SURFACE CONDITION	DRY





VISIBILITY DATA

NEAR SIDE	47
MIDDLE	47
OFF SIDE	16
TOTAL	110
" PERCENTAGE	73



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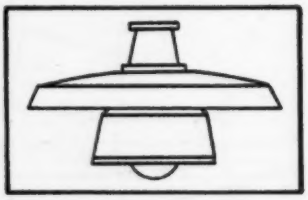
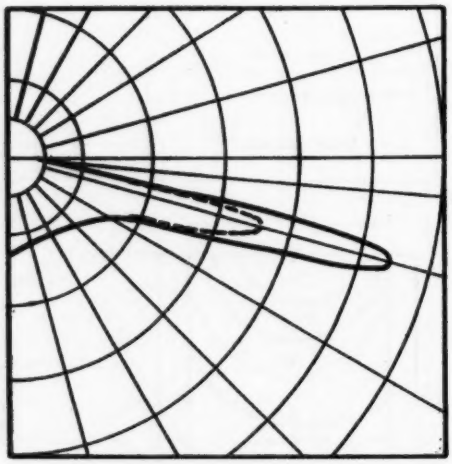
HORIZONTAL LIGHT INTENSITY AT EYE LEVEL

DIRECT FROM FITTINGS	0·0775
REFLECTED FROM ROAD	0·0025
GLARE INDEX	31

23

FITTING	TWO-PIECE AXIAL-ASYM DOME
LAMP	40 WATT-CC-CLEAR
ANGLE OF MAX BEAM	75°
CUT OFF	VIRTUAL – MINUS 5°
SPACING HEIGHT RATIO	6 TO 1
TYPE OF INSTALLATION	CENTRAL
SURFACE CONDITION	DRY AND CLEAR





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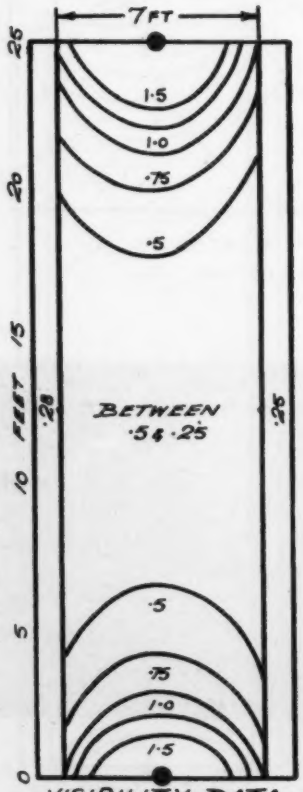


VISIBILITY DATA

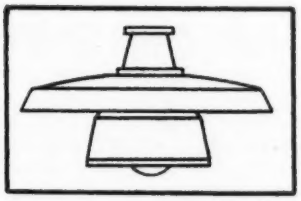
NEAR SIDE	50
MIDDLE	49
OFF SIDE	9
TOTAL	108
" PERCENTAGE	72

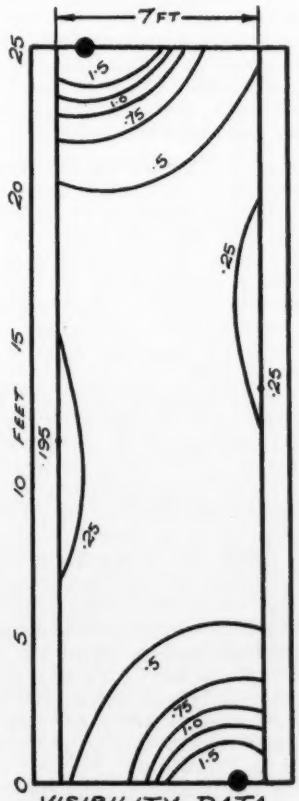
HORIZONTAL LIGHT INTENSITY AT EYE LEVEL

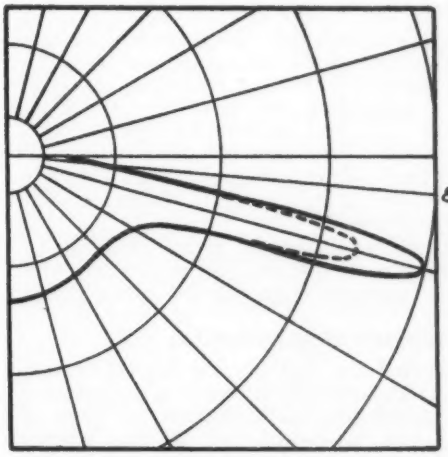
DIRECT FROM FITTINGS	0·104
REFLECTED FROM ROAD	0·0035
GLARE INDEX	29·7

26

FITTING	TWO-PIECE NON-AXIAL DOME
LAMP	40 WATT - CC - CLEAR
ANGLE OF MAX BEAM	75°
CUT OFF	VIRTUAL - MINUS 5°
SPACING HEIGHT RATIO	6 TO 1
TYPE OF INSTALLATION	STAGGERED — 1 FOOT OVERHANG
SURFACE CONDITION	DRY - QUARTER MOON - CLOUDY







— BOW AWAY FROM MIRROR
--- BOW TOWARDS MIRROR

VISIBILITY DATA

NEAR SIDE	40
MIDDLE	45
OFF SIDE	10
TOTAL	95
" PERCENTAGE	64

HORIZONTAL LIGHT INTENSITY AT EYE LEVEL

DIRECT FROM FITTINGS	0·0565
REFLECTED FROM ROAD	0·003
GLARE INDEX	18·8

THE REPRESENTATION OF STREET LANTERN CHARACTERISTICS

By R. MAXTED (B.E. Elec., B.E. Mech.)
(Member)

(Paper read on Tuesday, March 9th, 1937.)

Summary.

This paper examines from two points of view the problem of selecting suitable diagrams for representing lantern characteristics.

The subject is first considered in the light of a general investigation of the fundamental factors influencing visibility. In this an analysis of the optical designs of installations must be made in conjunction with a subjective survey of the visibility results achieved. A brief account of this work is given to show some of the considerations which influence the choice of lantern diagrams. Two simple diagrams which are of value in this work are suggested for general use.

The problem is also examined from the point of view of specifying a street-lighting installation, and it is shown that the same diagrams are suitable.

The General Investigation.

In earlier papers* the author and his colleagues have emphasised that road-lighting is a subject requiring two distinct lines of investigation. One is concerned with the determination of the effects which should be produced, and the other with the physical means of producing those results.

This may be said of all branches of engineering, and it may be added that a compromise is nearly always necessary in reaching a practical solution. But here the similarity generally ends, for in most branches of engineering both aspects of a problem are amenable to mathematical treatment with some degree of accuracy. In street-lighting, however, the goal can be only approximately defined as *visibility;* and the degree of visibility necessary, or the extent to which it has been achieved, is entirely a matter of the experience and judgment of all classes of road user.

But while the average observer is the only judge of the effectiveness of a lighting installation, he cannot state his requirements precisely in terms of physical measurements. In addition he has little knowledge of the economic and technical limitations, and is therefore unable to suggest a practical solution.

In predetermining the effect to be aimed at the lighting engineer has to thread his way between the physiological and psychological processes of perception, and embark upon a subjective investigation.

A method of carrying out such an investigation was described in the papers referred to above, and it was shown that reliable data could thus be obtained upon the *relative* effectiveness of groups of actual installations under normal conditions of use. The results are based mainly upon the judgment of experienced motorists and pedestrians who have no technical knowledge of the subject—"a little learning is a dangerous thing"—and are, as far as can be ascertained, unbiased. The observers assess the installations whilst travelling by car or on foot, and therefore experience any effects introduced by the speed of the observer. The result is expressed in an "order of merit."

If this method is used in a survey of many modern installations, including experimental types, these can be grouped as giving good, bad, or indifferent results. It is reasonable to expect that a comparison of the optical designs of the installations so grouped will lead to a greater knowledge of the factors influencing visibility, and ultimately to optimum lantern designs and installation layouts.

Objective Factors To Be Analysed.

In planning such an investigation it is inevitable that some difficulty will be experienced in linking up the subjective and the objective aspects of so complex a problem. It is of vital importance that *all* the optical effects produced by an installation should be recognised and analysed, and that the installation or lantern characteristics producing them should be recorded in suitable physical units for the purposes of an objective study.

Thus, if one installation is found to be superior to another, little will be learnt if an explanation is sought from a comparison of surface brightness only. For whilst these are essential effects their value to the observer is entirely qualified by the degree of glare produced by the installation. In a similar manner the perception of an object on the road does not depend only upon the background brightness, but upon the brightness contrast between the object and the background. It is therefore necessary to consider the manner in which the lanterns illuminate the object. The normal speeds and paths of the observer must also be taken into account, for some degree of repetitive glare may be produced as successive lanterns are approached and passed. At high speeds this effect may become of primary importance, with unsuitable light distribution.

Hence, installation design must be examined from two points of view—that of providing suitable brightnesses of backgrounds and objects, and that of avoiding or limiting the neutralising effects of glare. The mechanism of brightness production can be studied* with mathematical precision, and it is possible to determine the lantern light distribution

* "The Importance of Kinematical Factors in Roadway Illumination." By L. J. Davies, R. Maxted, and G. S. Lucas. (A.P.L.E. Conference, 1935.) Illum. Eng., Nov., 1935, p. 381.

* "The Application of Subjective Methods to Street-lighting Problems." R. Maxted. (I.E.S., Manchester, February, 1936.)

* J. M. Waldram. (A.P.L.E., 1934.) Illum. Eng., 1934; Oct., p. 305; Nov., p. 339.

which produces on a given road surface an optimum bright area. Unfortunately it is light which has been projected towards the observer for the purpose of producing surface brightness, which may also give rise to glare.

If it is proposed to modify a lantern distribution with a view to reducing glare, then the surface brightness must also be changed, and an optimum lantern design can be obtained only by a compromise between the requirements for surface brightness and glare. This compromise can be arrived at only by a careful analysis of the results obtained in the street with various forms of light distribution.

The Need for Lantern Curves.

From these considerations it is evident that much attention must be given to the selection of suitable methods of recording the design characteristics of installations. The point to be borne in mind is that whilst the light distribution of the lantern must be examined from several points of view, the various effects cannot be independently controlled with a fixed road surface, and the distribution must be regarded as an indivisible whole.

This is not to say that one diagram or set of curves must be made to serve all aspects, and it will be seen that the curves most suited for portraying the suitability of a lantern in producing surface brightness are not of any value in studying glare.

Direct glare from the lanterns is a matter between the observer and the lantern and there is no intermediate agency. It is therefore obvious that some form of lantern curve, such as the polar curve or the iso-candle diagram, is essential in studying glare.

Surface brightness, however, is the joint product of lantern light distribution and surface reflectivity and it may be argued that as the observer is concerned only with the light leaving the road surface. brightness diagrams should be used in representing the lantern performance. These diagrams would show the results produced by a lantern on a number of typical surfaces.

Brightness diagrams must, however, be interpreted in terms of the lantern distribution producing them when an attempt is made to effect a compromise between surface brightness and glare, and for this purpose the iso-foot-candle diagram is preferred.

It is readily seen that these two diagrams can be correctly interchanged when it is realised that for any surface there is a fixed relationship between the way in which light is incident upon the surface, and the manner in which it proceeds from the surface to the observer's eye. The iso-foot-candle diagram represents the light incident upon the surface, the brightness diagram the manner in which it proceeds from the surface to the eye, and these two diagrams are interlinked by the reflectivity diagram.

This, then, is the background against which it is proposed to study lantern curves, and like many backgrounds in street lighting it forms a large part of the picture. But before considering in detail the applications of these curves, it should be emphasised that the value of any diagram depends largely upon how clear a conception of the problem is given. This is certainly an argument in favour of the iso-foot-candle diagram, and with regard to the iso-candle diagram, it must be said that to those who will master it, this diagram is of the utmost value.

The Study of Glare and Cut Off.

Measurements of surface brightness are of importance in describing a part at least of the complete effect produced in a street. Glare, however, cannot be described satisfactorily in terms of brightness, for whilst an excessive source brightness may result in discomfort glare, disability glare is a function of the intensity and of the angle of light projected towards the eye. Similarly, repetitive glare effects arise mainly from variation in these factors produced by movement of the observer.

For a study of glare effects it is therefore necessary to record the precise manner in which light is projected from the lantern, and to correlate this data with the normal path and speed of the observer and the positioning of the lanterns.

In determining the intensity and direction of the light falling on the eyes for any position of the observer relative to a lantern, the iso-candle diagram of Fig. 1 can be used. On this are represented both

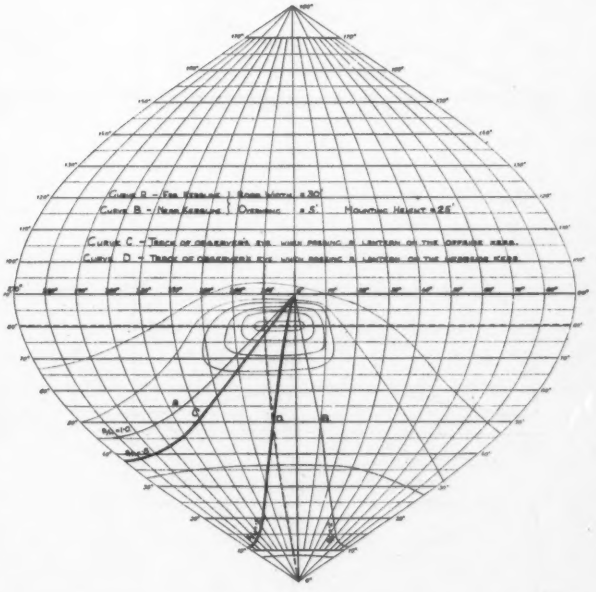


Fig. 1

the complete lantern distribution and the tracks C and D of the head of the observer as the lantern is approached from either direction. Along these tracks can be read off the intensity, vertical angle and azimuthal angle of light impinging upon the eye at any point in the path of the observer, and from this data any desired calculations can be made. It should be noted that data obtained in this manner may differ considerably from that taken from the vertical

dotted line shown in Fig. 1. This line represents the polar curve in a vertical plane through the main beam.

If, however, only the intensity and vertical angle are considered for vertical angles between 60° and 90°, a fair approximation is obtained from the vertical polar curve, provided that the main beam is sufficiently wide in azimuth.

In Fig. 2 are shown qualitatively the effects experienced with varying degrees of cut-off, the corresponding polar curves being shown to the right of each diagram. It is seen that with no cut-off below the horizontal, the accumulation of glare from distant lanterns tends to swamp the varying glare from lantern B as the observer moves from A to B. With this type of distribution repetitive effects should be negligible unless the candle-power changes rapidly at lower vertical angles.

With the severe cut-off shown in the second diagram the reverse is the case for there is no

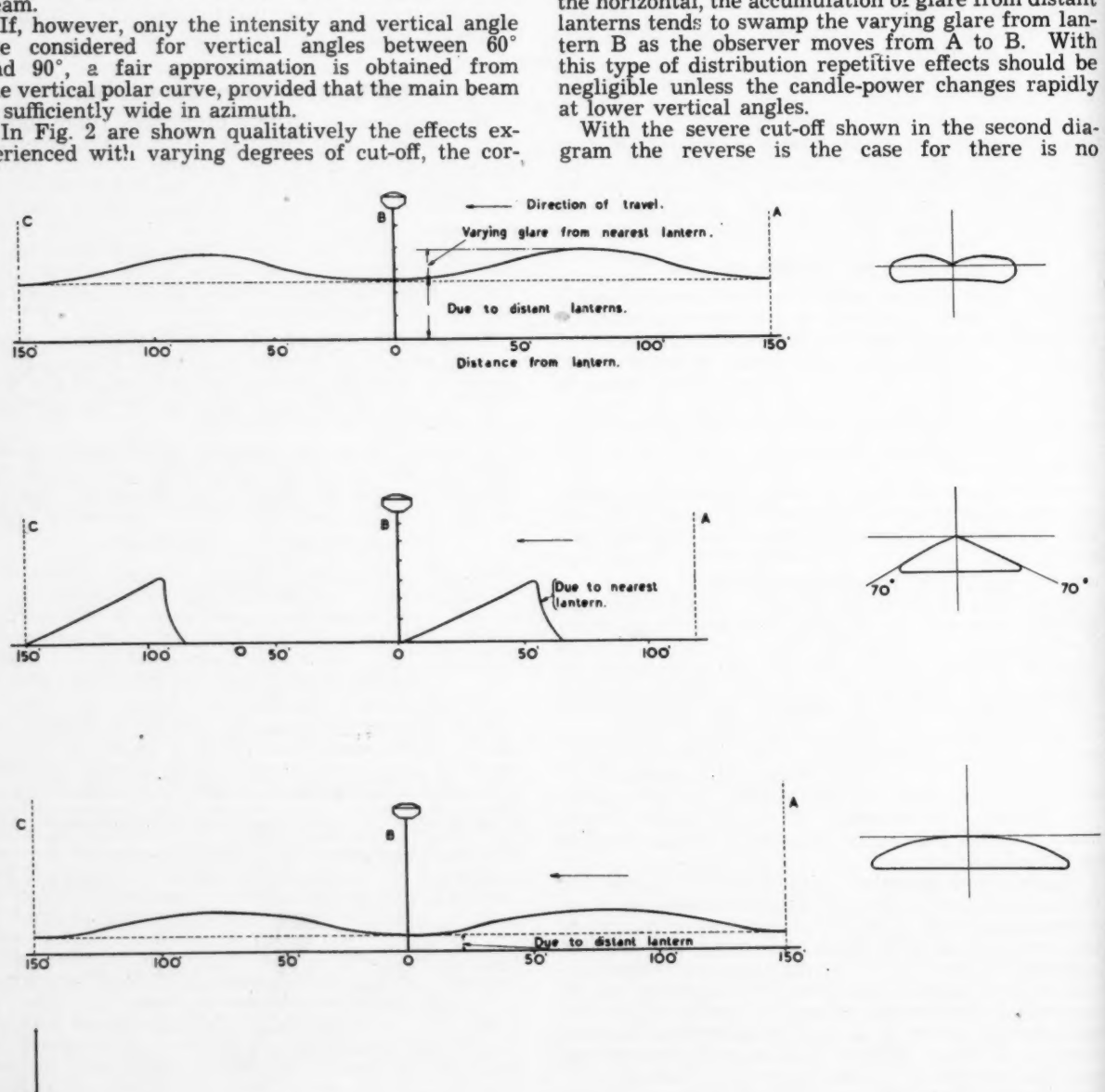


Fig. 2.

"reservoir" of glare from distant lanterns to keep the eye adapted. As a result, when the cut-off line is passed, very severe glare is experienced suddenly, and this decreases to zero as the lantern is reached. This effect is repeated as each lantern is approached, the frequency being about 22 per minute at a speed of 30 m.p.h. The effect of this upon the driver of an open car can well be imagined, and even in a saloon car giving a cut-off below 70° the effect of flaring of a wet or dusty windscreen, and of parts of the car body, is very disconcerting.

The controlled or graduated cut-off illustrated in the third diagram of Fig. 2 indicates the compromise to be sought. Here lower intensities at the horizontal provide just sufficient continuous glare from distant lanterns to avoid repetitive effects, provided that the rate of change of candle-power gradient, $\frac{dI}{d\theta}$, is within suitable limits. Repetitive glare effects can be examined to some extent apart from road brightness, and a separate laboratory study can be made of suitable limits for $\frac{dI}{d\theta}$ at various vertical angles.

The vertical polar curve through the main beam is suitable for general use in forming an approximate opinion of the lantern distribution in regard to glare, for in addition to showing maximum candle-powers, the shape of the curve will indicate excessive candle-power gradients.

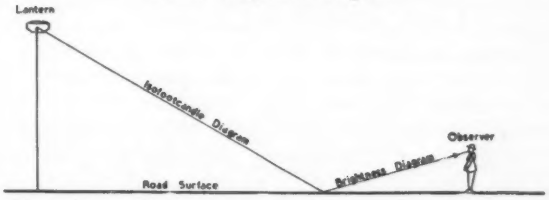
It should be noted that a cut-off which appears as almost a straight line on the polar curve may be entirely satisfactory if it occurs at a vertical angle of about 80° or higher. This is due to the fact that the vertical angle corresponding to the observer's position is changing very slowly with movement of the observer, and the lowest diagram of Fig. 2 illustrates this point. It will be seen that a cut-off beginning at 80° and ending at 85° would be spread over 140 ft. of the road length. Such a cut-off having even an appreciable component still at 85° will, owing to the nature of the polar diagram, appear as almost a straight line and may erroneously be judged as too sharp.

The Iso-foot-Candle Diagram.

Reference has already been made to the relationship between the Brightness diagram and the isofoot-candle diagram (I.F.C.D.), and this is represented pictorially in Fig. 3. The I.F.C.D. defines fully the manner in which light is received at any point on the road surface from the one lantern, and is therefore of fundamental value. From the lower diagram of Fig. 3 it is clear that the angle of azimuth and the angle of incidence of the light falling on any part of the road surface can be scaled off directly from the diagram, and, in fact, the scales could be drawn on the diagram.

It is necessary to consider at this stage the way in which the foot-candle values should be represented, for there is some misunderstanding on this point. It is customary to regard the I.F.C.D. as suitable only for representing so-called "horizontal illumination." According to the method proposed the actual intensity striking the horizontal surface is multiplied by the cosine of the angle of incidence, and the resulting vertical component of the incident intensity is

The Relationship between the Isofootcandle Diagram and the Brightness Diagram.



The Isofootcandle Diagram defines the manner in which light is projected on to the road surface.

The Brightness Diagram defines the manner in which this light is reflected off the road surface.

The Reflection Characteristics of a road surface can be determined from the Isofootcandle and Brightness Diagrams.

With a knowledge of the Reflection Characteristics of a road surface the Brightness Diagram can be calculated from the Isofootcandle diagram.

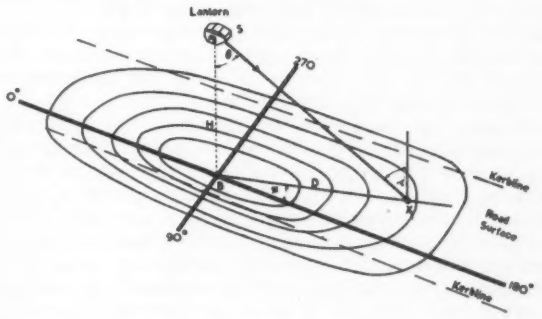
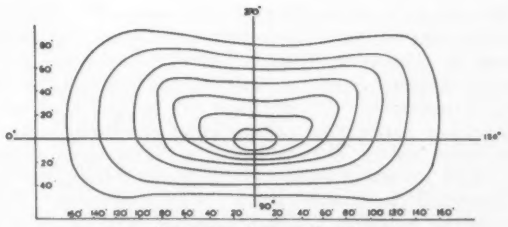
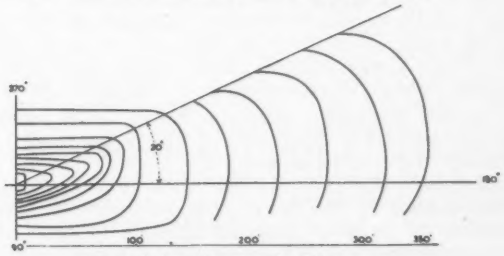


Fig. 3.



Typical Isofootcandle Diagram.
The values shown are vertical components only.



Extended Isofootcandle Diagram.
The intensities shown are measured normal to the light rays.

Fig. 4.

charted as shown in the upper diagram of Fig 4. This vertical component is, of course, a mythical quantity, and admittedly the transformation is of more interest in industrial lighting than in street lighting.

However, this does not fundamentally alter the value of the diagram, and, of course, has no effect whatsoever upon the light or the lantern represented. It is, in fact, only necessary to divide by the cosine of the angle of incidence at any point to arrive at the incident intensity, and the diagram yields all the information required in brightness calculations.

Under these circumstances, the I.F.C.D. has been of peculiar value during a period when the conception of horizontal illumination has been slowly giving ground to that of specular reflections.

With the object of avoiding confusion and of facilitating calculations where spread-specular reflection is considered, it is suggested that the I.F.C.D. should show the intensities measured on surfaces normal to the incident rays. Such a diagram does, indeed, give a clearer conception of the problem and is illustrated in the lower part of Fig. 4.

It may be suggested that the iso-foot-candle diagram should be drawn in perspective form, as in the case of the brightness diagram, to which it is so closely related. It must be remembered, however, that all such perspective diagrams are each drawn for one particular position of the observer relative to the lantern. The I.F.C.D. drawn in plan shows the manner in which light is received by the road surface over the entire area within the normal influence of the lantern, and brightness diagrams for all position of the observer can be derived from it. The brightness diagram can, of course, equally well be drawn in plan, and it is often convenient to do this.

With regard to the distances for which I.F.C.D.'s should be drawn, it will be noted that an extended diagram is shown in Fig. 4. With a staggered installation layout, and a spacing of 150 ft., it is generally necessary to continue the bright area produced by one lantern to just beyond the next lantern on the same side. This is in all a distance of about 350 ft., and in order that the diagram should not be too awkward in shape only half is shown. The beam spread is shown up to 20°, and it will be readily appreciated that this is not excessive when it is considered that the centre-line of a bright streak usefully follows the observer to angles of 30° to the road axis. This may be the case as an "off-side" lantern is approached, and more particularly at bends when the observer is on the inner kerb.

In the iso-candle diagram of Fig. 5 the boundaries of the two I.F.C. diagrams of Fig. 4 are shown. It is shown that an extended I.F.C.D. will closely define practically the entire useful distribution of a lantern, that shown by the heavy line "C" covering vertical angles up to 87°. It is of interest to compare this with the horizontal line at 80°, representing an 80° conical polar curve, and the vertical dotted line representing a vertical polar curve through the main beam.

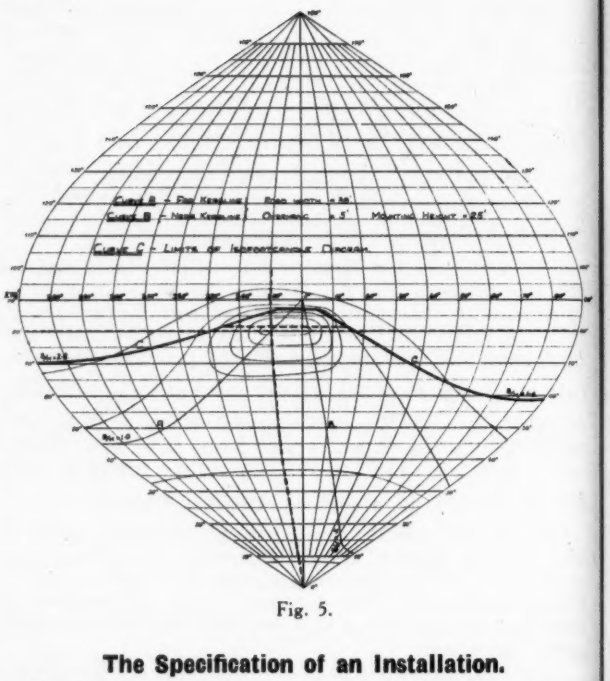


Fig. 5.

The Specification of an Installation.

In an analytical survey of street lighting, the records should cover the lantern characteristics, the distribution of brightness, and the location of units. A complete account of lantern distribution is given by the iso-candle diagram, and all other lantern curves can, of course, be derived from this paragon.

It has been stressed, however, that the I.F.C.D. and the polar curve give clearer conceptions of the two problems confronting the lighting engineer—the production of surface brightness and the control of glare. If critical analyses of the problem are to be generally undertaken—and this seems necessary in order to utilise fully the abundant experience now being obtained under various street conditions throughout the country—then lantern curves must be found which are both fundamental in nature and universally acceptable. For this reason it is suggested that the modified I.F.C.D. and the vertical polar curves are a better practical proposition than the iso-candle curve.

In the specification of an installation, also, these curves appear to offer a solution. For whilst it at first appears that a part at least of the result to be obtained could be specified in terms of brightness, there are practical difficulties. The variation in the reflection characteristics of a road surface, due to wear and to re-surfacing, make it impossible for a lighting engineer to guarantee a brightness result.

As it is necessary in any case to specify the location of lanterns and at least the maximum candle-power of the lantern in order to limit glare and to ensure a satisfactory ratio between object brightness and background brightness, it seems advisable to seek a specification based entirely upon the installation lay-outs and the lantern characteristics. Thus

the lantern distribution would be determined by the minimum size of the bright patch to be produced by an individual lantern when the road surface is in the least favourable condition. The installation layout would then place the lanterns so that the bright areas coalesced to give a satisfactory overall surface brightness from the normal path of the observer.

Such a specification avoids the abnormally wide tolerances which would accompany a brightness specification, and which it is to be hoped will be greatly reduced by more suitable road surfaces. In a specification of this type a vertical polar curve, in addition to the I.F.C.D., is desirable both in limiting glare and in ensuring that a low intensity—of the order of hundreds—is maintained up to the horizontal. This is required to add length to the bright streaks as they narrow down under wet road conditions.

The Lumen Basis of Lantern Curves.

In street lighting, where it is important that safe visibility should be provided under the worst conditions, it is, of course, advisable to allow a reasonable margin in all calculations. Thus, while the 400-watt H.P.M.V. electric discharge lamp gives an initial output of 18,000 lumens, it is suggested that curves of lantern performance should be based upon a perfectly clean lantern and a lamp output of, say, 12,000 lumens. With the lamp giving 16,000 lumens average over life, this allows a factor of safety of 33 1-3 per cent. to cover all other contingencies, such as variations in road surface reflectivity, efficiency of cleaning, accuracy of lantern erection, etc.

Coefficients of Utilisation.

When so much depends upon achieving an optimum relationship between the intensities projected in all directions from the lantern, it is obviously difficult to arrive at an intelligent measure of lantern efficiency.

However, as in the case of the effectiveness of an installation, a measure of the relative efficiency can be made for lanterns having similar forms of light distribution. Thus, if the lantern is considered to be mounted over an infinitely long road of a standard width, the total lumens falling upon the carriageway can be estimated from the iso-candle diagram.

This may be expressed as a percentage of the output of the bare source. It must be remembered that this is not the entire "efficiency" of the lantern, as light projected beyond the kerb lines is equally useful. Even so, where the entire lantern distributions are identical the figures give a direct comparison of efficiency.

Conclusion.

It should be emphasised that in making analytical comparisons of the factors which influence effectiveness, lantern curves should be chosen which give the easiest conception of the problem. A modified I.F.C.D. and a vertical polar curve are chosen, and they should be drawn with meticulous accuracy and carefully interpreted. As has been stated, the polar curve must be regarded with caution when it is used to form approximate opinions of lantern cut-offs at high vertical angles.

A point of particular importance should be made regarding the influence of colour when assessing effectiveness. Sources of different colour should not be mixed indiscriminately in a survey aimed at the study of lantern distributions, for the idiosyncrasies of various observers may well vitiate the results. A direct comparison of colour itself can be reliable only when identical lantern distributions and installation designs are considered under identical street and road surface conditions.

With regard to the applications of the modified I.F.C.D., it is suggested that this might ultimately be used in representing road surface characteristics directly in terms of suitable lantern distributions.

The author wishes to thank the directors of the British Thomson-Houston Co., Ltd., and Mr. Warren, Chief of the Research Laboratory, for permission to publish this data, and also to express his gratitude to Mr. Bertram for assistance in preparing the paper.

DISCUSSION

Mr. C. C. PATERSON said that he had been interested to see the effort which Mr. Maxted had made to reconcile the two main factors in street lighting, viz., the most ideal distribution to give the most favourable brightness with the minimum of glare.

Referring to the paper by Dr. English he noticed that the author stated that "The aim of street lighting is not to produce uniform illumination along the roadway, nor to produce uniform and high surface brightness, nor to eliminate glare, nor to produce a constant degree of glare, but simply to enable road users of whatever class they belonged to see clearly whatever they need to see, more particularly to see obstacles and circumstances that may lead to danger."

That seemed to him to be similar to saying that the designer of a motor car did not need to consider the H.P. of the engine nor the comfort of travelling in the car, and that all that was necessary was to have a car which would go along and give satisfaction! That might be true for the purchaser but not for the designer. Engineers who had been working at street lighting problems for the past ten and twelve years had been trying successfully to separate the variables and indicate the most important. If Dr. English now wished to mix them up again it seemed a pity that he must criticise the work of those who had been so carefully analysing the various factors which enter into street lighting—without presenting evidence that his own method gives a useful result. Criticism of others' work was most convincing when it followed rather than preceded the demonstration of their errors. He did not think that those who had

studied the independent variables had ignored their effect on the effectiveness of the lighting of streets.

Mr. E. J. STEWART said there were a few points not mentioned in the papers on which he would like to comment. The first was with regard to lighting committees whom it was difficult to induce to appreciate exactly what they saw under such scientific conditions as those usually employed by lighting engineers. In such circumstances it was, in practice, difficult to sort out the factors of glare, surface brightness, etc., in order to demonstrate to committees the value of any particular form of lighting. For example, a committee might be told that the lighting at a certain spot was really quite good, although to the eye the visibility might be affected by a bad background. The committee would still probably ask for another lamp.

Another factor was the proximity of one lighting installation to another; this affected the judgment of the observer and personally he was not sure how far it was possible to draw conclusions from a model street.

As regards glare, he sometimes wondered whether this was so serious, because after a short time there was a certain adaptation. A source of light which might at first seem to cause dazzle was found eventually not to be too uncomfortable.

He felt Dr. English had done well in stressing the importance of lighting not only for the driver but for the pedestrian. He wondered how far the use of glare screens on motor cars affected the importance of glare from lamps. These small screens were usually so low down that probably the drivers of cars so fitted hardly saw any of the lamps at all. As regards the pedestrian, he was not sure he agreed with Dr. English in saying that the importance of visibility for him was in his own near neighbourhood. He was inclined to think it was a question of observing obstructions in the road and that it was necessary to consider the "long" view in the case of pedestrians. A careful pedestrian in crossing a road would look to the right and left to see if any motor cars were coming, and if a motor car were 100 yards away it would be upon him before he got across. Therefore, the visibility of a motor car at that distance was a most important thing, and it was essential to see a silhouette of the vehicle against a bright surface on the roadway. It had been suggested that surface brightness would counteract glare, but a high surface brightness might actually contribute to glare. Therefore, it seemed better to have a moderate surface brightness all over than a high surface brightness which was not continuous all over the surface of the street.

He agreed with the final remark of Dr. English that at this stage of our knowledge we should not make recommendations or draw any conclusions.

Mr. J. S. PRESTON remarked that he had no special concern with street lighting, but that as a road user he was not convinced that being able to tell what an object looked like was quite the same thing as being able to tell whether it was there! It seemed that in Dr. English's tests the observer always knew that an object was present in view, whereas under actual street conditions, unsuspected obstructions were the ones least likely to be noticed and, therefore, most likely to be dangerous.

Mr. J. M. WALDRAM expressed interest in Mr. Maxted's method of presenting the lantern performance. The polar curve, or iso-candle diagram, had always seemed to him a rather unsatisfactory form of expression of the distribution, and was difficult to interpret. He felt that Mr. Maxted had hit upon a solution which would be very valuable in many ways, and would probably be useful in the calculation of brightness distributions.

With regard to the paper by Dr. English, he said that those who had been working in this country on the theoretical side of street lighting had endeavoured not merely to study one part of the problem, but to look at it as a whole; and although a knowledge of the whole truth was still a very long way ahead, he could not help feeling that Dr. English had not given sufficient credit for what had been achieved. It was necessary to consider all the individual factors concerned and to give each its due emphasis. Until recently it had not been possible to take account at all of some of the more important factors involved in the problem of street lighting; but now more and more was being learned about them; and although more attention might at the moment have been given to certain factors, that did not imply that the others had been overlooked.

Referring to the visibility test, Mr. Waldram said the difficulty was that as soon as any figure was placed upon visibility, people began to form conclusions. Therefore, when any visibility test was put forward it should be carefully examined to see what value could be placed upon it. A good deal of work had been done in this country in connection with the Ministry of Transport. Unfortunately, nothing could be said about it at the moment, but when it was published, as he hoped it would be at a later date, it might have some bearing on the methods which Dr. English had used and the results which he had obtained. There were certain conditions with which any test of visibility should comply, if it were to be of any use. The first and most obvious was that it should measure visibility, and not something else. That immediately involved the question of definition, and he could not help feeling that Dr. English had embarked on his experimental work without sufficiently defining what he wanted to measure. He was inclined to think Dr. English was measuring visual acuity and not visibility, two quantities which had no very close connection.

Two other conditions with which a visibility test should comply were (2) that it should be removed as far as possible from empiricism, and (3) that it should be possible to analyse the results of the test, in order to see how they were produced. The test which had been put forward violated these three conditions, and he felt that no great reliance could be placed upon the indications which it gave. He appreciated the hard work which Dr. English had put

into this difficult problem, but he could not help feeling that too much reliance should not be placed upon the results obtained until he was sure he was measuring what we wanted to know. It might confuse the whole of street lighting if uncertain figures for visibility were produced.

Mr. F. C. SMITH said that, having had some experience in investigating street lighting problems, he felt that Dr. English had done a wise thing in giving a timely word of warning to those engaged in this work. The paper this evening had brought investigators back again to basic ideas. It was a very necessary thing for someone with an analytical mind to come forward occasionally and bring investigators up with an abrupt stop, and compel them to consider whether they were really going on the right lines. Personally, he would take the advice of Dr. English to heart, in the spirit in which it had been offered. At the same time, he was satisfied that Dr. English would be the first to recognise the enormous amount of highly skilled work that had been accomplished. Referring to the work that Dr. English had reported to the meeting this evening, Mr. Smith said that he thought that it was very courageous to attempt singlehandedly to assess that difficult thing which was often referred to under the ill-defined term of "visibility." It was very necessary that this term as applied to street lighting should be defined more precisely, and he would say very frankly that he did not know whether Dr. English was measuring the particular quality which they all desired to measure in street lighting, or whether, in fact, he was measuring something akin to visual acuity. There were very many points in the paper which called for careful study, and he hoped that those working on similar lines would review the work Dr. English had done with the greatest care.

Continuing, Mr. Smith emphasised the difficulty of drawing conclusions based on this method of test or any other method of test, from work done in a model street, or even on work done in any one street. It was necessary to examine the various factors affecting that property which we called "visibility," and be able to control them, and where possible to alter them one by one, otherwise it was very easy to fall into error. He took it that Dr. English had regarded objects seen in reverse silhouette as visible, or had he concerned himself only with objects seen by ordinary silhouette. He noted that Dr. English had adopted a reflection factor for objects seen on the road of 12 per cent. Dr. English must have had some very good reason for adopting that figure, and he would be glad to know this. Again, Dr. English in his visibility tests measurements had made observations along the kerb, along the centre of the road, and on the offside of the road. Did he attach equal importance to the figures obtained on the near side of the road, or did he propose to weight the figures in terms of the relative importance under practical conditions of these various tracts of the road. As far as he understood it, the method proposed by Dr. English was a static method. He would be glad to know if Dr. English thought that the kinematic conditions obtaining in the street would introduce a factor which would vitally disturb his calculations.

Remarking that he thought Dr. English had started at the right end in regarding distribution from the sources as of the utmost importance, Mr. Smith said that in his personal opinion the question of distribution was a factor which had been somewhat overlooked in much of the work which had been done on visibility. It would be a good thing if future workers on visibility in the streets paid more attention to the distribution factor.

For a long time, engineers had wanted a yard stick to measure "visibility." Moreover, it was extremely important that the results obtained from the use of this yard stick should be capable of analysis, in order that it might be possible to design an installation and get predetermined results.

He hoped, however, that Dr. English would not regard the results he had obtained, as indicating anything more than tendencies. At the same time he would look into this work with great interest, to see if the facts could be analysed with a view to giving assistance in planning street lighting installations to give predetermined results.

In conclusion, Mr. Smith apologised to Mr. Maxted for having devoted so much time to Dr. English's paper, and leaving so little time to discuss Mr. Maxted's contribution, but he would, however, study this paper with the greatest interest. At the moment he was not sure that he agreed with Mr. Maxted's views as to the effect of cut-off reflectors, and would like to argue that with him at a later date. However, in Mr. Maxted's paper there was a great deal which no doubt could be made use of when the question of redrafting street lighting specifications was under consideration.

Mr. J. S. Dow remarked that, in applying the iso-foot-candle diagram as a basis for specifications, Mr. Maxted seemed to imply that the nature of the street surface would not be taken into consideration. Would his method be applied in the same manner to a tarmacadam road, which was dark and shiny and to a new concrete surface which was light and relatively free from polish?

Mr. Dow also asked Mr. Maxted what had been his experience in trying to explain the iso-candle diagram to non-technical people. No doubt those who were taking part in this discussion would find no difficulty, but those who were not experts seemed to find this particular diagram exceedingly difficult to understand.

One drawback to efforts to assess the qualities of a lighting installation in physical terms was the difference in behaviour of the eye at high and low illuminations. It might well be—as had been suggested at the last meeting of the Society—that a given relative variation (numerical contrast) in brightness of a road-surface which was scarcely noticeable at very low illumination became much more evident when the order of illumination was higher. He wondered whether Dr. English, in the course of his tests, had found evidence of this effect.

Mr. C. A. MORTON remarked that a clear coiled-coil lamp was probably not the most satisfactory for use

as a lamp in a model street. It has not an identical light distribution in all vertical planes. The asymmetry is less marked when an internally frosted finish is used. A single-coil filament in a clear lamp would probably have been better suited, for here this asymmetry largely disappears. It is probable that the most satisfactory lamp to use would be one having a similar light distribution to the normal high-wattage filament lamp. A suggestion would be the general service clear 230-volt 25-watt type lamp. A further handicap resulting from the use of the clear coiled-coil lamp for experiments like Dr. English's is, that as the filament is a short arc, it cannot be mounted at the centre of the lamp, so that when used in a fitting of the cut-off type, the cut-off angle, which has received considerable attention in the paper, is not the same in all directions.

With regard to Mr. Maxted's paper, Mr. Morton suggested that the term "surface brightness" should be qualified by a statement of the particular surface to which reference is being made. The surface brightness of the carriageway, footway, and buildings all enter the problem in addition to the surface brightness of the fitting.

Mr. A. R. McGIBBON suggested that the Society or the Association of Public Lighting Engineers should endeavour to seek co-operation with road engineers in order to agree on the nature of road surfaces in relation to the lighting of them. At present, road engineers expected the lighting engineer to light satisfactorily any road surface, and the problem was becoming an increasingly difficult one. Therefore, some collaboration of the nature he had suggested would be very helpful.

Some people, including some Lighting Committees, seemed actually to like glare. Perhaps it was the spectacular effect which attracted such people, or it might be due to over-enthusiastic salesmen, who did not fully appreciate the requirements of good street lighting.

Referring to Mr. Maxted's paper, he asked which was the best shape of light source to produce the best road brightness. Should the source be a point or a large surface or a long one?

Mr. R. G. HOPKINSON said that he would like to comment on Dr. English's photographic work, as a reference had been given to the standard representation technique which he (Mr. Hopkinson) had described to the Society at a previous meeting. He thought it would be generally agreed that before an article is described as following a given specification, every effort should be made to ensure that the specification is followed in every respect. From the appearance of Dr. English's photographs, it would appear that, although they are quite untouched in any way, it would not be correct to say that they followed the standard representation technique. If this had been done, the exposures would have been very different with installations of such widely differing average brightness, and yet Dr. English had given the same exposure in every case. Again, the photographs appeared to be very much too contrasty; yet one of the essential points of the standard representation technique is that the contrast should be unity. It was not correct for Dr. English to say that, as he had given the same exposure to his plate in each case, his photographs were necessarily comparable amongst themselves. The characteristics of photographic materials and the properties of the eye render the problem very much more complex than is generally realised. One presumes that the photographs were intended to give an impression, not of the photographs as such, but of the characteristics of the installations which Dr. English was describing. If this was their function, the only way in which the correct impression could be conveyed was by following the standard representation technique in all its details. The technique was not simply a guide to exposure and printing time, but was based on the physiological characteristics of the eye.

Mr. F. J. TAYLOR said the object in street lighting was to *see*, and for that it was necessary to have high contrast sensibility. Without that it was impossible to see with the low brightnesses used on roads. He asked Dr. English why he chose a brass disc, and whether with the square recess he was able to get high contrast to the bright surface of the road.

Mr. PERCY GOOD said he was coming to the conclusion that too much time was being spent in hunting for the basic ideas, and he was beginning to think that a great deal of street lighting required to be looked at from a somewhat different point of view. Remarking that a meal was digested the better according to the manner in which it was served, Mr. Good suggested that some attention should be given to getting a satisfactory and nice-looking job by studying something of the amenities as well as road brightness or visibility. There were a large number of streets in which such a form of illumination would be more effective and desirable, and there were miles of streets which should be treated in this way.

There was one feature about Mr. Maxted's paper which he welcomed, and that was that when attempting to make a specification which would deal with buying and selling a commodity, it would be a great deal better if conformity with that specification could be measured in a test room or laboratory.

Dr. J. W. T. WALSH (communicated) said that he would like to join issue with Dr. English in regard to one or two points in his most interesting paper. The chief of these was the way in which he assessed glare. The value of the glare index was obviously quite independent of the distribution of brightness on the roadway, so long as the total amount of light reaching the eye from the road surface remained the same. It seemed very doubtful whether this corresponded with the facts, and, indeed, Dr. English himself cast doubt on the matter when he explained that the value of the index was misleading in the case of a wet (or otherwise polished) surface. Inci-

dentally, the higher values of glare index must be liable to considerable error, since the denominator is the differences between two much larger quantities which were, in this case, very nearly equal. For example, in tests Nos. 22, 23, and 24, if all the "direct light" values were decreased by 2 per cent. (the figures of total illumination being left unchanged) the "glare index" figures would become 15, 19, and 20 respectively.

The method of measuring visibility also seemed to be open to criticism in that a disc six inches in diameter, placed as described in the paper, occupied a not inconsiderable area of the projected surface of the roadway. In these circumstances one would expect the results to be very indefinite owing to widely varying contrasts between the brightness of the surface of the disc and that of the opening at the various possible positions of arrest. In view of these facts alone it seemed very dangerous to draw any such conclusions as those contained in the last paragraph but two of the paper; most street lighting engineers would be more wholeheartedly with Dr. English in urging the caution he so well enjoined a few lines further on.

DR. S. ENGLISH, in reply to the discussion, said he would like to thank those who had so freely joined in the discussion of this paper. Before answering individual points, he would like to give a collective answer to those gentlemen who had commented on the method he had used to assess visibility. The most general criticism was that the method measured something akin to visual acuity. He agreed that the 1-in. square recess in the rim of the disc was on the small side, but it had been deliberately chosen so as to make it difficult to detect except under very suitable seeing conditions. This was done in order not to get 100 per cent. visibility except under abnormally good conditions, and thus permit differentiation between systems which were quite good. Despite the criticism regarding the smallness of the recess, it was a fact that when conditions were suitable it could be seen quite easily.

Dr. English did not agree that the test he had used failed to attain any of the three conditions for a visibility test set up by Mr. Waldram, and contended that it gave a better measure of "visibility"—(since it was affected naturally by the four chief factors that affect visibility, namely, brightness of background, brightness of object, order of illumination and glare) —than could be obtained by measuring these factors separately and compounding them in a way that may or may not be correct.

Dealing with the further points on this topic raised by Mr. Smith, Dr. English said that when the position of the recess in the disc was visible by "reversed" silhouette, it was included and was shown in the table of results as "direct vision." The reflection factor of 12 per cent. for the surface of the disc was admittedly high, but here again, it was so chosen as to make it difficult to get 100 per cent. correct readings except under abnormally perfect conditions. (This also answered Mr. Taylor's point.) No attempt had been made to weight the visibility readings according to their location across the roadway, but realising that visibility along the near side of the road was more important than along the middle, and that in turn more important than along the off side of the road, the results for these three locations had been given separately, so that "weighting" could be applied by anyone who so desired.

The static conditions of the test rendered detection more difficult than kinematic conditions would have done, so that any system of lighting that gave good visibility under the test conditions would necessarily give good seeing conditions when movement assisted vision.

It was true, as Dr. Walsh pointed out, that the test disc covered a considerable projected area of roadway, the brightness conditions of which may, and in fact in many cases did, vary considerably, but so far from this being regarded as a criticism of the method, it might be regarded as a point in its favour, since the recess corresponded to objects standing at different heights from the road surface—corresponding on a full size road to objects from 6 in. to 3 ft. high. By taking ten readings as each point, it was felt that a fair average visibility of objects between these two heights was obtained.

Mr. Preston raised an interesting point regarding the possibility of seeing unsuspected objects. It was difficult to see how a fair test to meet his point could be devised, but Dr. English thought it was safe to say that if an object that was known to be there could be seen more clearly under one set of conditions than another, then an "unsuspected" object was also more likely to be seen under that set of conditions.

Replying to Mr. Paterson's remark Dr. English said that the "mixing up" of the various complex factors involved in street lighting should not be laid to his charge. Anyone making use of a street by night found these factors all simultaneously in operation, and was guided by their aggregate effect, as indeed was mentioned both by Mr. Stewart and Mr. Good in their contributions to the discussion. He had merely tried to reproduce, more or less imperfectly, the joint effect in a street, but under conditions which enabled the various factors to be assessed separately. He did not wish Mr. Paterson or others to think that he undervalued the excellent work that had been done in certain directions, for example, in studying road surface brightness. He did think, however, along with many engineers, not only throughout Britain but throughout the world, that when attention was concentrated on this admittedly important item there was a danger that insufficient weight might be given to some other factors, such as, e.g., the glare arising from light emitted at angles slightly below the horizontal.

Dr. English was glad to hear that the work he had included in the paper had the general approval of Mr. Stewart, who had such a wide practical experience of street lighting and the problems it involved. Although he had not yet come to any definite conclusions—as was emphasised in the paper—he was inclined to agree with Mr. Stewart that perhaps the best seeing conditions would be obtained with a

moderate uniform road brightness obtained without excessive glare. He hoped to have something to say on this point at a later date.

Answering Mr. Dow, Dr. English said that in the present piece of work he had limited himself to the effect of light distribution on visibility, and therefore had obtained no data regarding the brightness contrasts necessary at different levels of illumination.

He was glad Mr. Morton had corroborated the remarks found in the paper concerning the unsymmetrical light-distribution given by the clear 40-watt coiled coil lamp. Mr. Morton suggested that a 25-watt lamp would have been better, but a 40-watt lamp was necessary to give the desired illumination.

Dr. English agreed with Mr. McGibbon that co-operation between the road surveyor and the lighting engineer was very advisable. At the present time, the road surveyor often did not appreciate the difficult task he set the lighting engineer when he laid down a practically matt black surface.

He could not agree with the arguments put forward by Mr. Hopkinson, and though not a photographic specialist himself he took his stand on the opinions of friends who were employed as chemists and physicists in the photographic industry and who presumably knew the properties and the limitations of their products.

Dr. Walsh was perfectly right in drawing attention to the fact that the glare index given in the paper was by no means a precise measure of glare—nor could it be used as a general method of estimating glare. It was only used in the work under consideration as an indication of the severity or otherwise of glare, and it was pointed out that even as such it could only be used when the test road surface was dry. If the road surface were wet or otherwise highly polished, the light reflected by such surface, instead of mitigating glare by giving a light background, would in fact act as a secondary glare source.

Mr. R. Maxted, replying to the discussion on his paper, thanked Messrs. Paterson, Waldram, and Smith for their kind remarks.

In reply to Mr. Dow, he stated that the nature of the road surface would not be neglected in his method of street lighting specification. The light distribution required by various types of surface would be predetermined experimentally, and it was quite possible that these would differ sufficiently to necessitate more than one specification. As regards the iso-candle diagram, he agreed that it could not be used in explanations to non-technical people. It was found, however, that the layman appreciated the iso-foot-candle diagram, and this was an additional argument for the form of lighting specification advocated.

In reply to Mr. McGibbon, Mr. Maxted said he would not express an opinion upon the relative merits of the shapes of light sources. It must be left to the fittings designer to produce the best result he could from the shape of light source he had available.

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